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ENGINEERING DESIGN HANDBOOK FOR AIR CLEANING FOR CHEMICAL DEMILITARIZATION

LEVEL

by

Marvin E. Siegel (AAI Corp.)
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March 1978

Contract No. DAAA15-75-C-0154
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US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

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The purpose of this handbook is to provide information and references relating to the design of an air-cleaning system for chemical demilitarization operations. The goal of the system is the highly efficient removal of toxic chemical agents in the form of minute particulate, aerosol, and gaseous matter.

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20. Abstract (continued)

The handbook is intended primarily for engineers and other technical personnel who are responsible for designing air-cleaning systems capable of meeting the stringent requirements imposed by public law and other regulations relating to the safeguarding of the health and safety of workers and the environmental quality of air discharged to the atmosphere. It is the intent of this handbook to point out the many areas of concern and to provide recommendations and precautions based on previous experience with such systems.

The air-cleaning system discussed here, patterned after that extensively used in the nuclear industry, was developed by the Chemical Systems Laboratory (CSL) of the U.S. Army Armament Research and Development Command (DARCOM) and is presently installed at the Chemical Agent Munitions Disposal System (CAMDS) facility located at Tooele Army Depot, Utah. The experience gained as a result of this application is documented here to provide baseline data for designers of future systems for demilitarization operations and other similar applications (e.g., chemical laboratories).

Criteria for establishing the air volume, airflow, and sizing of the air-handling equipment are presented. Consideration is given to hood locations, ductwork and damper performance, filter housings, particulate filters, gas-phase adsorbers, blowers, and instrumentation for testing, monitoring, detection and control.

Discussions also cover installation, testing, maintenance, and operation of the ventilation and exhaust systems.

Since the major hazard to be removed is in gas or vapor form, the air-cleaning system, as designed, provides a minimum exhaust gas residence time of 0.25 second through the first of two identical adsorber banks. The second adsorber bank provides a backup adsorption capacity in the event of a breakthrough of the first stage. A GB-challenge test was actually conducted on one of the filter units installed in the CAMDS facility. This test successfully confirmed the efficiency of the system in removing GB agent.

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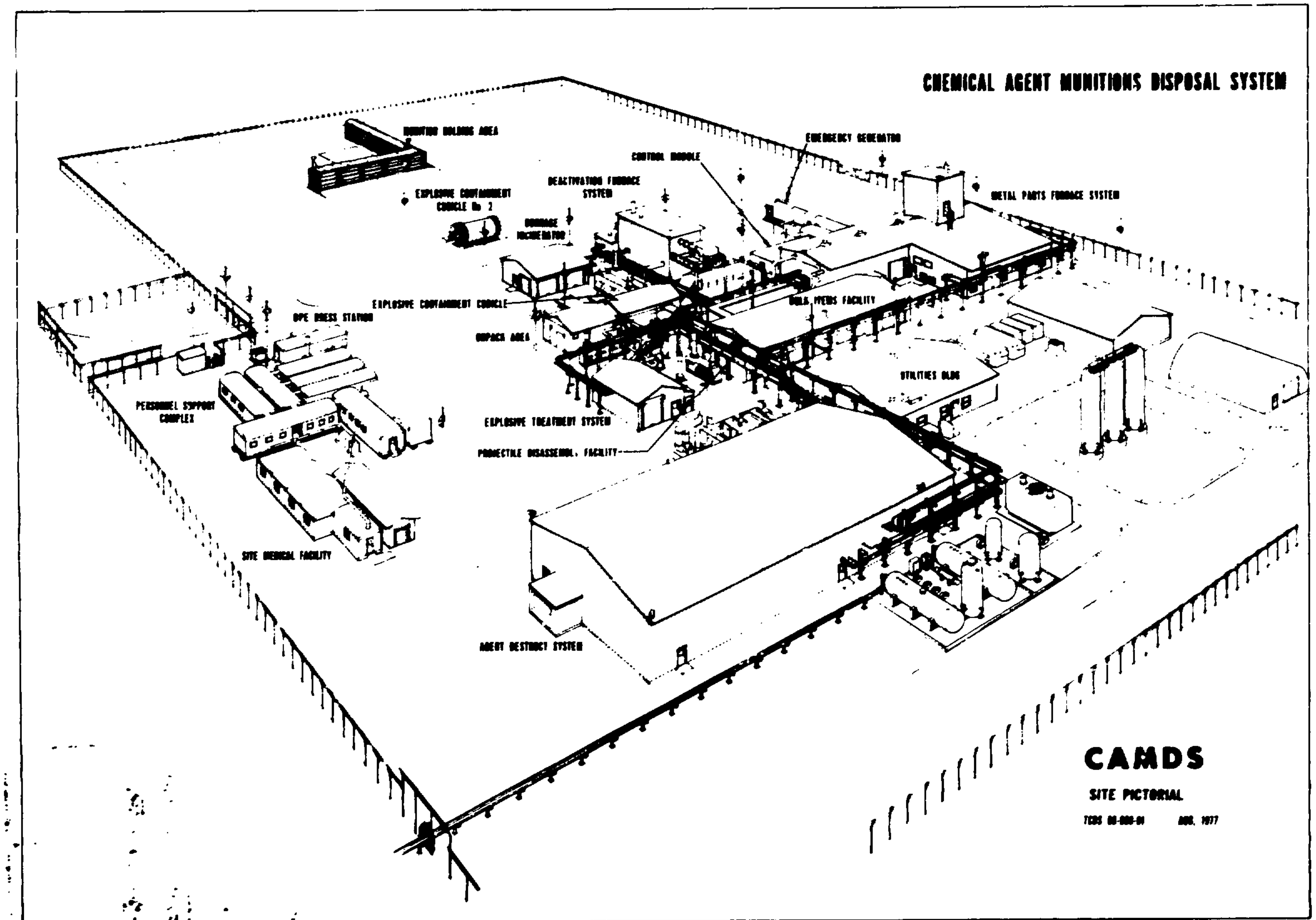

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Chemical Systems Laboratory
Aberdeen Proving Ground, Maryland 21010

ABSTRACT

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The handbook is intended primarily for engineers and other technical personnel who are responsible for designing air-cleaning systems capable of meeting the stringent requirements imposed by public law and other regulations relating to the safeguarding of the health and safety of workers and the environmental quality of air discharged to the atmosphere. It is the intent of this handbook to point out the many areas of concern and to provide recommendations and precautions based on previous experience with such systems.

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PREFACE

This handbook was prepared by AAI Corporation, Cockeysville, Maryland 21204, as Task No. 52-7US4001M-1E200 of Contract No. DAAA 15-75-C-6154 for the Chemical Systems Laboratory, Aberdeen Proving Ground, Maryland 21010. Funding was provided to CSL by the Project Manager for Chemical Demilitarization and Installation Restoration (PM/CDIR) under Department of the Army Project No. 655, "Emission Studies."

This document, which was written during the period October 1977 through March 1978, is readily available to all elements of the U.S. Army Development and Readiness Command, other Government agencies, and contractors who have a justifiable requirement for same. Comments and suggestions on this publication are welcome and should be addressed to:

Commander/Director
Chemical System Laboratory
Aberdeen Proving Ground, Maryland 21010
Attn: DRDAR-CLT-D

The information provided here should be considered as advisory only. The equipment and techniques described have been successfully applied in CAMDS prototype operations, but this is not to imply that they will be equally effective in other similar applications.

Trade names and names of commercial suppliers are mentioned in this document as a means of providing more specific identification of the products used. However, such mention is not to be construed as advertising or as implying that the U.S. Government endorses or approves of their use.

Permission has been granted by the U.S. Department of Energy and American Conference of Governmental Industrial Hygienists to quote material from their copyrighted publications "Nuclear Air-Cleaning Handbook" and "Industrial Ventilation - A Manual of Recommended Practice," respectively.

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1. INTRODUCTION

1.1. Purpose

This engineering design handbook is specifically addressed to exhaust ventilation and effluent gas air-cleaning systems for use in chemical demilitarization operations involving highly toxic chemical agents and related munitions. Its purpose is to provide engineering design information for determining the basic filter equipment and accessory instrumentation needed for meeting environmental and occupational air quality standards.

1.2. Scope

The scope of this document is limited to chemical demilitarization activities; however, its general approach is also applicable to other similar operations such as chemical laboratories and chemical agent production and processing.

A chemical demil ventilation system is concerned with removing chemical agents and reaction by-products in the form of minute particulates, aerosols, vapor, and gaseous matter. Consequently, this handbook places emphasis on the adsorbers (or gas filters) as well as the high-efficiency particulate air (HEPA) filters. The added presence of a roughing air filter (or prefilter) assists in prolonging the effectiveness and life of the filter system by screening out larger extraneous materials.

1.3. Discussion

The principles and design of the chemical demil air-cleaning system described in this handbook are parallel in many respects to those successfully employed in the nuclear industry. Both applications involve highly sophisticated designs not readily amenable to the conventional design practices of standard heating and ventilation systems.

Extensive experience has already been gained with the air-cleaning system installed in the present CAMDS* site at Tooele Army Depot, Utah. This facility, however, is a prototype plant and at this writing has not yet been placed in full operation. Thus, some of the information contained in this handbook may be revised as more operational experience becomes available.

*Chemical Agent Munitions Disposal System

The overriding consideration in the design of a filter system for chemical demil usage is the safety of the plant operating personnel, the surrounding populace, and the general environment. To ensure personnel and environmental safety the filter system must be designed to meet specified control values or limits in regard to:

1. Work areas
2. Stack emission
3. Ambient air quality
4. Site perimeter

Limit values approved for the CAMDS demil facility by the Office of the Surgeon General, Department of the Army, in regard to the above categories are listed in Appendix A. (Similar values have been proposed, but not yet approved, for other demil applications.) These limits and control levels represent values that are detectable by existing instrumentation for the specified chemical agents (GB, VX, and mustard); they are not necessarily the minimum values desired. Lower limits may be established in the future upon the availability of more sensitive instruments. In actuality, operating and emission limits should be kept as far below these limits as practicable even though they may not be detectable by present means.

Much information pertaining to ventilation and air-cleaning systems already exists in previously issued publications. The practice followed in this handbook is to reference information of interest which may be found in readily available standards or textbook and to quote from pertinent information contained in less accessible government reports. Consult section 9 for a complete list of the references cited in this handbook.

2. REQUIREMENTS FOR AIR CLEANING FILTRATION SYSTEMS

2.1. Positive Pressure Versus Negative Pressure

Filtration systems generally considered for achieving "clean" air may operate by either of two methods - positive pressure or negative pressure - depending upon whether the air is intended for use within an enclosure or for release to the atmosphere.

2.1.1. Positive Pressure

Clean-air supply systems are used to protect a sealed enclosure from outside contamination. In this type of system, the filters are located in a contaminated area with the blower situated upstream. This produces a positive pressure in the filter system with respect to the surrounding atmosphere and prevents the infiltration of contamination. Figure 2-1 illustrates a typical positive pressure system.

Typical situations using this type of filtration system for protection are clean rooms, military command posts, communication centers, medical facilities, etc. The positive-pressure concept, however, does not lend itself to chemical demil air-cleaning plant operations where the desired airflow is in the opposite direction. For design handbooks dealing further with positive pressure systems, consult references 1 and 2.*

2.1.2. Negative Pressure

Filtered exhaust systems are used to contain contamination within an enclosure or hood and prevent its release to the outside. In this type of system, the filters are located in a clean area with the blower situated downstream. This produces a negative pressure in the filter system with respect to the surrounding atmosphere and prevents any unfiltered air in the filter system from penetrating the surrounding area. An example of a typical negative pressure system is shown in figure 2-2.

This type of exhaust air cleaning system, which is principally found in chemical laboratories and chemical agent/munitions loading and manufacturing facilities, is also suitable for chemical demil operations and is, therefore, the only type subsequently discussed in this handbook.

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*References are listed in section 9.

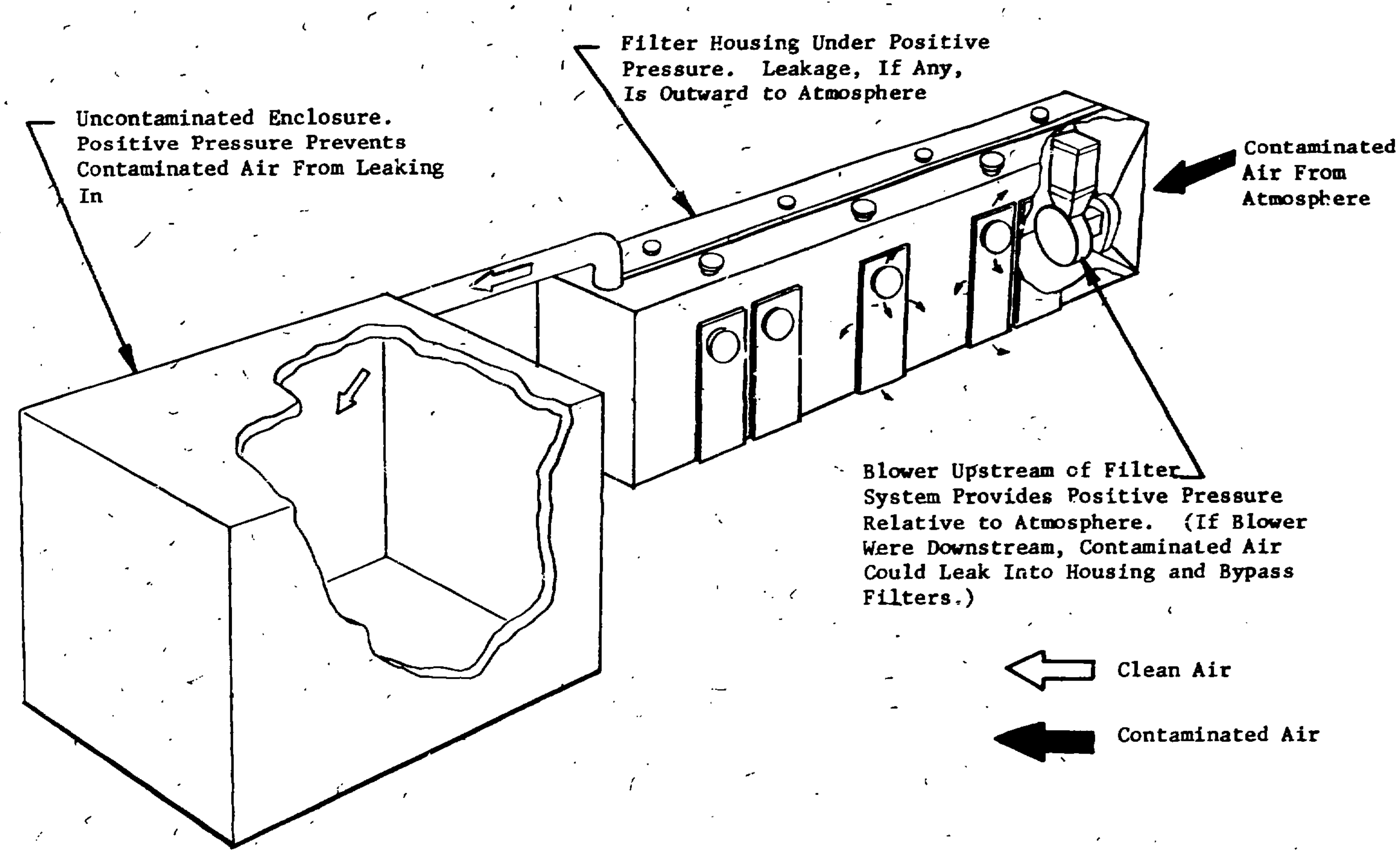

Figure 2-1. Positive Pressure Filter System

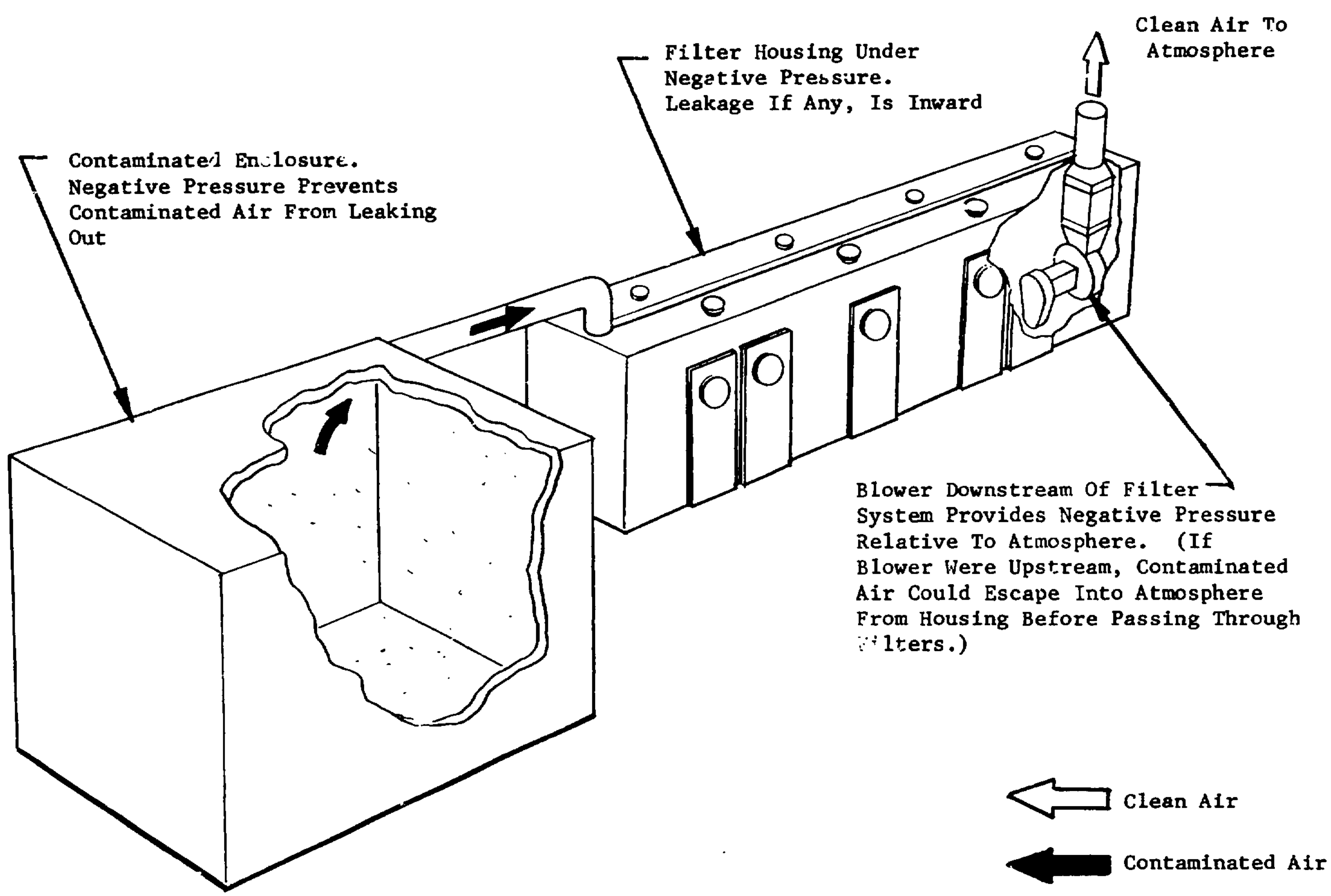

Figure 2-2. Negative Pressure Filter System

2.2. Atmospheric/Occupational Standards

2.2.1. Standards

Since chemical demilitarization facilities and laboratories handling toxic agents operate under negative pressure with respect to atmospheric pressure,[3*] their ventilation systems must be operated in the exhaust mode. Such systems must be designed to meet the following stringent atmospheric/occupational exposure limits to insure the safety of personnel and the environment:

1. Work Area Limits (see table A-1 in Appendix A)
2. Stack Emission Limits (see table A-2 in Appendix A)
3. Ambient Air Quality Limits (see table A-3 in Appendix A)

These established limits or control levels are not to be considered allowable in the sense that the designer's concern is only with equal or higher levels, but rather that operating and emission limits should be kept as far below the control levels or limits as practicable.

2.2.2. Regulated and Nonregulated Areas

Regulated and nonregulated areas** are established in a chemical demilitarization facility based upon the anticipated operations to be performed there. The method of determining the exhaust volume required to provide adequate ventilation in these areas is then dependent upon whether the area is declared regulated or nonregulated.

Local exhaust ventilation is utilized to capture and remove agent vapors released in regulated areas. Such areas are designed to maintain a negative pressure with respect to adjacent areas. (See section 4.2.) In addition to determining the local exhaust ventilation rates and the negative pressure requirements, the ventilation rate needed to maintain the desired indoor temperature must also be determined.

Operations performed in nonregulated areas are not expected to release agent into the work area. Therefore, the ventilation rate for these areas is determined by the activity being conducted and the volume of air required to provide the desired indoor temperature. Nonregulated areas are also maintained at negative pressure with respect to atmospheric pressure.

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*Superscript numbers refer to references listed in section 9.
**See glossary (section 10) for definitions.

All openings into regulated areas through which personnel enter or exit must be provided with airlocks to prevent the outward flow of contaminated air. Specific design guidelines for airlocks are provided in section 4.2.3. The airlocks should be ventilated at a rate which ensures that migration does not occur from the regulated areas. This means that sufficient air should be passed through the airlocks to provide adequate scavenging of any contaminants that might have entered. The airflow should always be from the nonregulated (clean) area to the regulated (potentially contaminated) area.

2.2.3. Laboratories

All laboratory chemical-fume hoods in which agents are used should be ventilated at a minimum rate of 150 cubic feet per minute (cfm) per square foot of open hood area (which is equivalent to a minimum of 150 feet per minute (fpm) inward velocity when measured at the open hood face). Crossdrafts can be avoided by proper placement of inlet openings. The laboratory must be maintained at a negative pressure.

2.3. Unique Negative Pressure Systems

While extensive use has been made of negative pressure systems in, for example, nuclear applications and chemical laboratories, most applications involving chemical agent contamination have employed either chemical treatment (e.g., scrubbers) or conventional filtration equipment (e.g., CBR filters). Recent demilitarization operations at CAMDS, however, have employed, to a limited extent, the more efficient equipment used in nuclear applications.

CAMDS, an ongoing major program of the Office of Project Manager, Chemical Demilitarization and Installation Restoration (PMCDIR), is a prototype demil system for all lethal chemical agents/munitions (except Wet Eye) now in the US inventory. To carry out its mission, PMCDIR funded the U.S. Army Chemical Systems Laboratory (CSL) to determine the best ventilation and filter design for demil operations. This effort resulted in the exhaust-air containment and cleaning system now installed at the CAMDS facility. This system has been successfully tested on site against agent GB and is judged to be a significant improvement over conventional chemical-treatment and CBR-type filter units for handling and filtering ventilation air from chemical demil operations. Its principal features are:

1. Use of metal frames and housings for containing the mechanical filters and adsorbers.

2. Redundant installation of adsorbers in series, with a detector between the adsorber banks to warn of agent "breakthrough" through the first bank. A second bank in reserve helps to assure that no chemical agent escapes to the environment.

3. Limited parallel redundancy between filter systems for contaminated areas.

4. Mechanical and electrical provisions throughout which facilitate maintenance and provide necessary checks on proper installation and in-service performance.

5. Maximum utilization of standardized, commercially available components.

Another disposal system designed by CSL, relying heavily on the CAMDS experience, is DATS (Drill and Agent Transfer System). It is discussed in detail in section 8.

2.4. Elements of Exhaust System

The major elements of the exhaust (negative pressure) air cleaning system are:

1. Filter housing

2. Internal components:

   Prefilter
   HEPA filter
   Adsorber
   Blower

3. External components:

   Ductwork
   Dampers
   Exhaust stack
   Local exhaust hoods
   Controls and instrumentation

All of these elements are necessary in each system and are discussed in general terms in section 3.

3. BASIC DESIGN CONSIDERATIONS FOR EXHAUST SYSTEM

The design of an exhaust ventilation system must include provisions to localize and remove virtually all agent from the airstream prior to exhausting to the outside environment. Included in the sections that follow is a general discussion of the basic design considerations essential to an exhaust system for use in chemical agent demil operations.

3.1. Agent Vapor Removal Methods

3.1.1. Methods Available

Most agent vapors can effectively be removed from the process exhaust air stream by one or more of the following methods:

1. Physical adsorption on a spongelike surface of attracting material, such as activated carbon, alumina, or ion-exchange resin.

2. Absorption by intimate scrubbing with a stable solvent.

3. Chemical reaction, as with sodium hydroxide, in a packed gas scrubber.

4. Combustion into harmless basic oxides by incineration.

This handbook assumes that the necessary engineering evaluation and selection process has been completed and that the designer has justified the use of a combination adsorption (for agent vapors) and mechanical (for particulate matter) air cleaning system as subsequently described.

3.1.2. Adsorption

Adsorption is a process whereby molecules of a fluid contact and adhere to the microcrystalline pore structure of a solid phase material known as an adsorbent. Gases, liquids, or solids can be selectively captured and removed from a fluid stream with adsorbents.

The basic adsorbent materials are silica, alumina, and carbon. In air-pollution control applications, the most common adsorbent is coconut-base carbon manufactured by controlled decomposition under a steam atmosphere. Carbon manufactured by this process is commonly called activated carbon.* Activated carbon is usually preferred to other adsorbents in pollution control work.

*Activated carbon can also be produced from other base materials such as wood and coal.

In the design of a pollution control system utilizing activated carbon, consideration must be given to the cleanliness and temperature of the contaminated gas, physical parameters of the activated carbon, regeneration means, where applicable, and recovery or disposal of wastes from the system.

An adsorption system can be combined with a separate mechanical filtering system (for physically removing particulate and aerosol matter) to provide a filtration system capable of removing all types of contaminated material.

3.2. Criteria for Determining Ventilation Rates

The ventilation system for a demil enclosure must provide adequate airflow to capture and exhaust agent vapors from contaminated work areas, provide adequate temperature control in uncontaminated work areas, provide adequate airflow between designated contaminated and uncontaminated areas, and maintain the enclosures at a specified negative pressure.

The first element to be determined is the type of operation to be performed in the enclosure. If the operation is such that agent release to the work area is highly probable, the ventilation system must have sufficient capacity to capture agent vapors at the point of generation and transport them to the air-cleaning equipment. The following general rules should be followed in designing hoods for toxic materials:

1. Use enclosing hoods whenever feasible, otherwise, place freestanding hoods as close as possible to the agent source.

2. Avoid crossdrafts that may spread contamination.

3. Furnish and distribute makeup air to ensure sweeping of agent vapors toward exhaust points and precluding or minimizing stagnant area.

4. Construct contaminated area away from outside walls to avoid wind pressure directly on walls of the toxic enclosure.

It is only after the hood design has been selected that exhaust volume requirements can be determined. (Refer to Chapter 4 of reference 4.) Detailed information on hood design is provided in section 4.2.1. With enclosures, volumes are calculated from the known open area of the hood and an indraft velocity of at least 150 fpm, which should be sufficient to prevent outward escapement. When free-standing hoods are used, they must be designed such that a capture

velocity of 150 fpm is maintained in the area of generation to ensure conveying the contaminant to the hood opening.

In enclosures where the operation is not expected to release agent vapors, the ventilation system must be designed to provide heat control. Methods for calculating these flow rates are contained in references 5 and 6.

When an opening between contaminated and uncontaminated areas exists, an influent velocity of at least 150 fpm through this opening is necessary. In most instances, the volume of air required for heat control or local exhaust ventilation will be sufficient to meet this criteria. When designing airlocks, however, the supply of makeup air may have to be significantly increased. (See section 4.2.3 for a discussion of airlock design.)

As previously indicated, one function of the ventilation system is to maintain the enclosures, ductwork, and air-cleaning system housings at negative pressure to prevent contaminated air escaping from the system by any path other than through the filter system. The degree of negative pressure required is a function of several factors: (1) intended use of enclosure, (2) physical form and toxicity of chemical agent involved, (3) location within the facility, (4) surrounding environment, and (5) explosive nature of munition.

When determining negative pressure, consideration of the external pressure exerted on the building by winds must be included, unless the toxic enclosure is housed within a protective outer enclosure. If there is no outer enclosure, allowance should be made for effects due to: (1) average wind velocity, (2) prevailing wind direction, (3) seasonal and daily variations in velocity and direction, and (4) local wind interference by nearby buildings, hills, or other obstructions of similar nature as they relate to the building site.[5] Knowing the typical wind environment in which the facility will operate, a negative pressure value can be determined for preventing outleakage from the building. This value, in addition to those determined by previously mentioned factors, must also be used in establishing the negative pressure requirements for the enclosures. In actuality, wind will be a factor only if a wall of the contaminated area is integral with the exposed wall of the building.

Doors and openings in negative pressure facilities may require special opening mechanisms, i.e., hydraulic or pneumatic, to overcome the external pressure. Louvers or dampers may have to be specified, based on the known airflow and negative pressure requirements, to provide makeup air and to control the direction of airflow within the contaminated area.

Contaminant control by air dilution is not acceptable for demilitarization operations because of the extreme toxicity of the chemical agents involved and the inadequacy of predicting the generation rate of the agent. Designs based on number of air changes per hour (dilution ventilation) or other rule-of-thumb methods are inadequate since they generally result in unsuccessful operation or in excessive and unnecessarily high cost of installation and operation.

3.3. Filter Capacity

In designing a filter system, the capacity and efficiency required are based upon the maximum challenge concentration anticipated and the length of time this challenge may exist before corrective action can be taken. To determine the worst-case (accidental) challenge condition, the designer must review all operations, devise a series of accident scenarios, and calculate the resulting challenge to the filter for each case. Although a determination of this nature is somewhat subjective, the calculations must reflect the worst conditions of airflow, spill size, and temperature to assure that, in fact, a worst-case situation is derived. This estimate can be refined later as more data becomes available. (The result of such a study for CAMDS is covered in section 4.1.1.3.2.).

Once the worst-case challenge is determined, the reduction ratio (and, hence, capacity) required by the filter housing may be computed from the formula,

$$\frac{C_o}{C_i} = R_{min.}$$

where:

C_o = concentration out (maximum allowable stack emission)

C_i = concentration in (worst-case challenge)

$R_{min.}$ = minimum agent reduction ratio required by filter system

The minimum capacity required (in mg-min/m^3) is obtained by multiplying the worst-case challenge by the time required for cleanup to be significantly effective.

3.4. Safety

The overriding consideration in the design of a contamination containment and filtered exhaust system is to guarantee the safety of plant operating personnel, the surrounding populace, and the general environment. To meet this requirement, several safeguards must be incorporated into the basic ventilation package.

The design of a system meeting demil requirements is not a difficult task if one assumes that the system will always operate properly. Difficulty arises, however, in designing a system that continues to fulfill its basic requirements even if a malfunction or failure occurs. Since a malfunction or failure of any component of the system could result in contamination of the environment and injury or death to personnel, the design of the total system must provide backup or redundant features to continue containment in the event of the loss of a primary system. Two design techniques for incorporating redundancy into the basic filter design are series redundancy and parallel redundancy.

Older filter systems usually contained only one bank of sufficient capacity of each filter and adsorber in series together with a chemical agent monitor/alarm located downstream. When the monitor indicated a breakthrough some contamination, up to the level of the monitor's alarm sensitivity, had already leaked into the atmosphere. This concept, however, is now unacceptable in view of the current stringent emission standards. One approach to the problem is the use of a series-redundant system containing two banks of the critical filtration components (i.e., the adsorber) in series with an agent monitor between the banks, as illustrated in figure 3-1.

With this type of redundant system, no contamination should ever reach the atmosphere. When breakthrough of the first adsorber bank occurs and the agent monitor activates, the second adsorber bank still provides complete protection until operations can be shut down and a new first bank installed. In theory, each of the two adsorber banks should be sized to provide the full adsorptive capacity required for the worst case expected. Thus, if the first bank is penetrated, a second bank providing complete protection would be already on line. However, in view of cost, space, and/or power limitations, it may not always be practical to have each adsorber bank provide 100% protection. (See section 4.2.9.)

Both adsorber banks of a series redundant system should be the same size and should, between them, provide the total adsorption capacity of the system. In case of a breakthrough by the first bank, as announced by the monitor, sufficient adsorption capacity remains in this bank to reduce the agent challenge concentration to the second bank until the operation can be shut down. As a consequence, the second bank suffers minimum agent intrusion and its life (and, hence, protection) is prolonged.[6] Another safety feature to be incorporated into the filtering system is parallel redundancy.

This involves a completely separate (secondary) system through which airflow can be diverted if a malfunction or failure occurs in the primary filter system (see figure 3-2). The two independent systems of a parallel-redundant filtration system contain series-redundant filters and adsorbers together with a dampering mechanism capable of switching between the two systems. As an added safety feature, each system must be connected to a different power source.

Parallel redundancy is required in many nuclear applications. For chemical demil use, however, total parallel redundancy may not be practical or necessary in view of cost, space, and power considerations. At the very least, however, a partial parallel backup is recommended. Its purpose is to provide sufficient airflow capacity to safely shut down all operations in the event of an emergency (i.e., to prevent contamination from entering clean areas or the atmosphere), rather than to provide sufficient capacity for continued operation. (See Section 4.2.9 for parallel concept used at CAMDS.)

Parallel redundancy at CAMDS is reflected by the requirement that at least two independent sources of power be available for all critical operating components. If the primary source is commercial, an on-site generator is required in the event that this source is lost. If, on the other hand, the primary power source is a generator - rather than commercial - a second generator is required. In the ideal situation, the backup power source should offer the same power output as the primary source. However, in a practical sense, the backup generator may be significantly smaller than the primary one. The purpose of the latter backup system is to provide sufficient power to key areas to enable the facility to be shut down without releasing contamination.

Belt-driven blowers are required to be equipped with a minimum of two belts (three belts minimum on large capacity units), so that if one belt breaks the other takes over and the blower continues operating.

In addition to redundancy, there are other safety features which can be incorporated into the ventilation system design criteria. For instance, in the event of a complete loss of airflow, it is essential that the highly contaminated areas be sealed airtight. This can be accomplished by the use of fail-safe (closed) pneumatically or electrically operated dampers. The dampers may be programmed to close when a power loss occurs or when there is no airflow through the filter. Leaktight ducts are also necessary to prevent contamination from migrating from the ductwork in case of airflow loss or when differential static pressure between the contaminated area and the outside enclosure drops below a predetermined value.

Properly designed instrumentation and agent monitoring systems are highly important in order to convey to control personnel information as

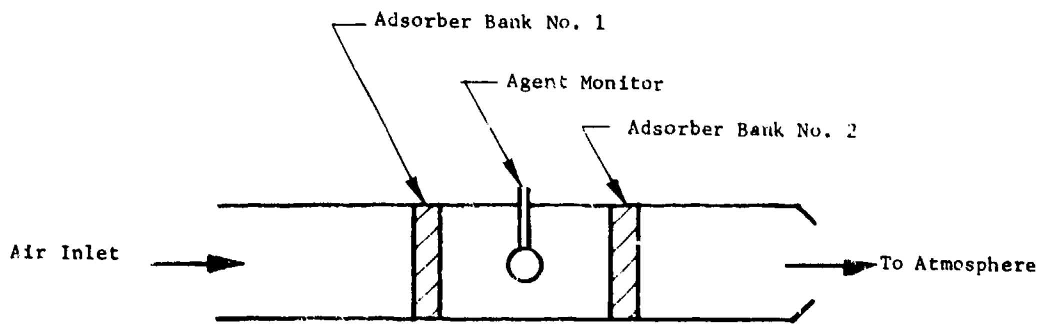


Figure 3-1. Schematic Of Series Redundant System

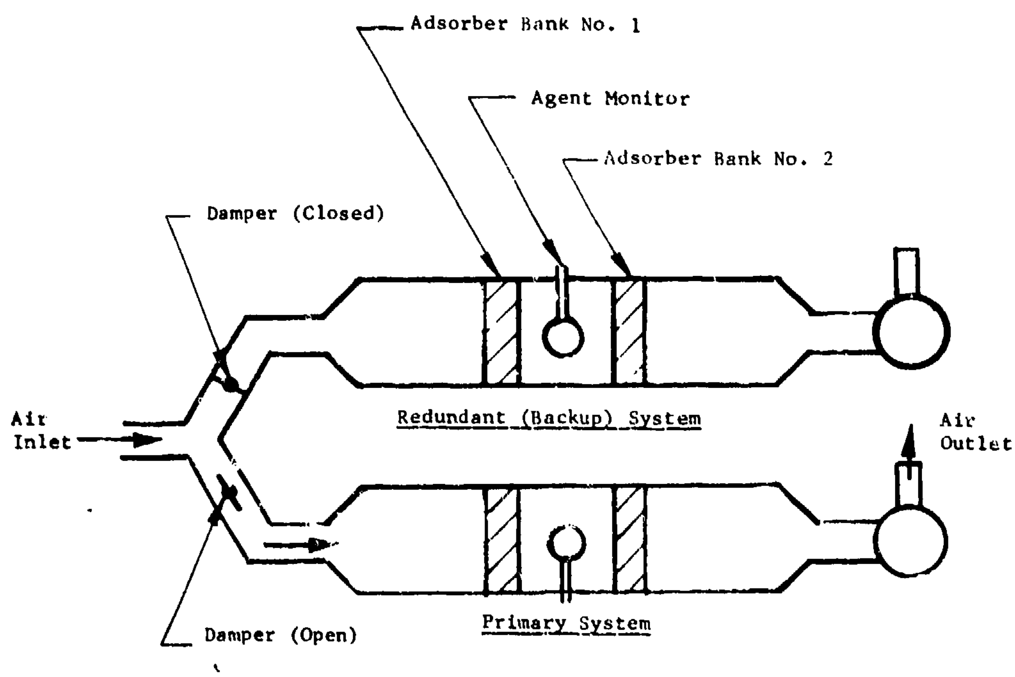


Figure 3-2. Schematic Of Parallel Redundant System

to when and where a malfunction occurs so that immediate corrective action may be taken. If the possibility of an explosion exists in any of the demil operations, special design considerations must be made. There must be assurance that no shock waves can penetrate the filter housing. This can be provided for by installing (1) a snubbing system, (2) a blast gate, or (3) a capability for closing off the exhaust ductwork from potentially dangerous operations.

Noise control is another requirement. In general, the ventilation system is to be designed in compliance with OSHA requirements for noise control. Since DA regulations governing acceptable sound (noise) levels are more restrictive than those of OSHA, the former shall apply. This means that the steady-state noise level of the system shall not exceed 85 db on Scale A of a standard sound-level meter.

See also section 5.4 for emergency considerations.

3.5. Operation and Description of Key Components

3.5.1. General

The key components of the basic ventilation package consists of air cleaning units, heating and ventilation units, and associated ductwork, dampers, hoods, controls and instrumentation. The ventilation system should be designed in accordance with the recommended practices given in references 4 and 7 and as stated in the system specifications.

The design objectives of the basic ventilation package are as follows:

1. Ensure total containment of all airborne contamination within all toxic enclosures by maintaining appropriate differential pressures and airflow between enclosures.

2. Localize contamination at the source for the protection of personnel by utilizing totally enclosed hoods, or if this is not physically possible, by utilizing capture hoods and differential pressures.

3. Remove agent from contaminated exhaust air prior to release to the atmosphere by exhausting air at a predetermined airflow rate and passing the air through a series of filters and adsorbers, scrubbers, or furnaces, or a combination thereof.

4. Ensure exhaust air meets stack emission requirements.

5. Ensure ventilation system provides work area in which atmospheric concentration of agents does not exceed maximum allowable concentrations.

3.5.2 Operation

In the operation of the ventilation system, all airflow must be from uncontaminated areas to contaminated or potentially contaminated areas, or from less-contaminated to more-contaminated areas. The air is drawn from contaminated enclosures at specified flow rates and velocities to ensure adequate agent capture and control as well as negative pressure within the enclosure. Differential pressures between contaminated enclosures and ambient areas are determined by the specific design constraints of the system.

In its flow through the ventilation system, the air is pulled into an airtight filter housing. The housing contains the required banks of air cleaning components, a blower, and provision for attaching an exhaust stack. After entering the filter housing and passing through its various stages, the decontaminated air flows out the exhaust stack to the atmosphere. At this point the formerly contaminated air should be sufficiently clean to meet stack emission limits.

3.5.3. Description of Ventilation System

3.5 3 1 Housing

The filter housing provides a complete airtight enclosure from the air inlet to the air outlet connection (stack) or at least to the blower. All necessary framing and structural supports for the filters and adsorbers are furnished as an integral part of the housing. The filter housing is generally constructed of carbon steel coated on all surfaces with a corrosion-resistant paint; stainless steel has also been used in small enclosures exposed to severe corrosion. The filter and adsorber mounting frames (where the potential for scratching of the mounting surface is minimal) are made from coated carbon steel, uncoated stainless steel (which affords better corrosion protection than carbon steel but is still subject to attack by certain chemicals), or, for maximum protection, coated stainless steel. Because of its smooth finish, epoxy-base paint minimizes potential agent penetration and, therefore, provides very satisfactory corrosion protection against most acidic or alkaline-type chemical attack.

To ensure that the housing is capable of meeting structural requirements, it must withstand without permanent deformation the pressure/vacuum tests and pressure-decay leaktest requirements stated in section 4.1.2.1.

In general, the housing configuration is dictated by the flow capacity of the filter system as well as the means for incorporating the adsorber media. For the purpose of this handbook, it is assumed that all filters are in the form of modular cells. For adsorbers, there are two available configurations, (1) a modular cell configuration, and (2) a fixed single unit rechargeable in place. These are described in section 4.1.3.3.

The standard Army CBR adsorber cell is of woodframe construction nailed and glued into a wooden housing. It does not lend itself, however, to the same level of efficiency as the types of adsorber systems discussed in this handbook.

3.5.3.2. Particulate Filters and Adsorber Cells

The filter housing can contain up to three different types of cells, referred to as prefilters, HEPA filters, and adsorbers.

1. Prefilters are low-efficiency fibrous filters for removing heavy concentrations of coarse particulate matter from the air stream. They are installed upstream of the HEPA filter.

2. HEPA (high efficiency particulate air) filters are extremely high efficiency, extended media fibrous filters for removing fine particulate matter and aerosols from the air stream.

3. Adsorbers are beds of granular material, usually activated carbon, which remove agent vapors by a chemical and/or physical adsorption process; they are not mechanical filters and their use applies to vapors and gases only.

Detailed descriptions of these elements are given in section 4.1.3.

3.5.3.3. Arrangement

The actual type and number of banks of cells required depends on several factors: (1) chemical composition and nature (i.e., particulate, gas) of the contaminant, (2) initial concentration, and (3) maximum concentration allowed in the exhaust air from the stack. For example, a building in a chemical demil facility requires both particulate and vapor filtration. Therefore, its filter system will contain prefilters, HEPA filters, and adsorbers. A clean-room facility requires only particulate filtration and thus needs only prefilters and HEPA filters, no adsorbers. The offgas filter system for a chemical agent decontamination tank filters agent vapors escaping from the munition through the decontamination solution; therefore, it requires only adsorbers.

Detailed specifications relating to filter/adsorber types and arrangements must be stringent. This is because the HEPA filters and adsorbers, the critical components of the filtration system, constitute the final barrier (or containment) between the contaminated area and the outside environment.

3.5.3.4. Instrumentation

Instrumentation is required to monitor and control the airflow through the filter system. The instrumentation must provide a means to monitor overall pressure drop as well as the pressure drop between the respective filter banks. The instrumentation must also provide the control signals required to maintain flow through the filter system at specified levels as a function of pressure drop.

In general, the increase in resistance as dust and particulate matter are trapped by the prefilters and HEPA filters is the largest variable pressure drop that must be accommodated by the system. This change in pressure (ΔP) is monitored with differential pressure gages. The readings thus obtained are used as a basis for changeout of these filters. (See section 6.4 for discussion on changeout criteria.)

Pressure buildup in adsorbers is prevented by catching all airborne particulates (the only component of the airstream causing ΔP) in the mechanical filters. Therefore, differential pressure gages are not required to monitor pressure drop across adsorber banks. Such instrumentation may be installed, if desired, for information purposes (but are not used as a basis for changeout). Changeout of adsorbers is based on breakthrough by chemical agents, as indicated by agent detectors (described in section 5.2).

3.5.3.5. Blower and Flow Control

The blower located at the downstream end of the filter housing provides the driving force for air movement. It consists of a motor, fan, drive, and mounting frame. The blower size is based on the flow rate and total static pressure requirements for the system. Factors such as altitude and temperature affect the flow rate calculation. The fact that the total static pressure of the system is not constant but increases with dust loading of the prefilters and HEPA filters is the major variable that must be considered.

When sizing the blower, first determine the flow rate requirements (adjusted for altitude and temperature), then calculate the anticipated static pressure that the blower will be required to overcome with clean filter cells installed. The static pressure requirement is then increased to allow for the increase in pressure drop as the prefilters and HEPA filters become clogged with dust. The "dirty filter" ΔP may be several times the "clean filter" ΔP. An additional pressure factor is added to compensate for uncontrolled air infiltration, pressure surges, and wind effects and to allow for possible future modifications of the ventilation system. It is possible to dampen an oversized blower, but if the blower is undersized, it cannot perform its design function and may have to be replaced. Setting the blower capacity at a level higher than that required for the initial application offers a degree of flexibility in providing for increased ventilation capacity for future applications. In

addition to flow rate and static pressure, other factors that must be considered in selecting a blower are given in section 4.1.2.11 and section 10 of reference 4.

Vibrations caused by the blower unit should be minimized by the use of vibration isolators and flexible connections wherever possible. Severe vibration can cause the carbon granules in the adsorbent to break up or powder and thus reduce the effectiveness of the adsorber cells.

Before the blower specification is finalized, the designer must determine the voltage and frequency of the power source and the voltage/frequency tolerance of the motors. Motors designed for one type of voltage rating; e.g., 3-phase 200-volt power is not interchangeable with 3-phase 230-volt power.

A flow-control system is required in conjunction with the blower. This includes a straightening section in the exhaust stack above the blower in which accurate airflow readings can be made. In CAMDS a gage with a specially calibrated scale reads velocity pressure in cfm. The flow control unit also provides a signal to the blower damper to enable the airflow of the system to remain constant despite variation in the total drop of the system.

3.6. External Components

External components of the filter system include ductwork, dampers, stacks, instruments and other items of the system concerned with the movement, control, conveying, and monitoring of airflow.

3.6.1. Ductwork

The ductwork is a part of the overall filtration system. It must meet stringent pressure and leaktightness requirements. Where potentially toxic exhaust is being transported, standard sheetmetal ductwork is unacceptable. All-welded, round duct with flanged connections is recommended; for small diameter applications, flanged pipe may be preferred.

The incorporation of sampling and test ports in the initial ductwork design is essential, otherwise holes may be indiscriminately made when testing is required. Sampling ports are required for the insertion of instruments to obtain flow measurements during air balancing of the system. When not in use for air balancing, the sampling ports can be used as access for instrumentation to monitor the upstream agent challenge concentration to the filter system. The ductwork is sized and layed out to minimize the pressure loss and to ensure that sufficient transport velocity is maintained in the duct to prevent settling out of contaminants in the air stream. (See section 4.2.2 for ductwork design.)

3.6.2. Dampers

Dampers are the valves of the air cleaning and ventilation system and are classified in terms of function/configuration, construction, and leaktightness. Clear, concise specifications must be established for, (1) mechanical strength, (2) leakage rate at maximum operating conditions, and (3) ability to perform under required operational and emergency conditions. All dampers are flange mounted with a gasket between the mating surfaces. Further information on dampers is covered in sections 4.2.5 and 5.3.

3.6.3. Exhaust Stacks

The design, type, and location of exhaust stacks are important to good dispersion of exhaust air to the atmosphere. Proper discharge design (e.g., stack height and location) must be followed to ensure that the exhaust air (potentially at a low level of contamination even if below minimum environmental requirements) does not re-enter adjacent buildings or work areas. In cases where it may be impractical or infeasible to construct a stack higher than an adjacent structure, it is recommended that cognizant air-pollution control authorities (federal, state, and/or local) be consulted for acceptable solutions to this, as well as other, types of problems. Under certain conditions, it may be beneficial to combine the filter system exhaust with another exhaust system and use a common stack. Again, as with ductwork, sampling ports must be incorporated into the exhaust stack. Their recommended locations, functions, and other factors are discussed further in section 4.1.2.13.

3.6.4. Other Items

Other external components required at the area being ventilated include heaters and alarm instrumentation (to indicate an upset in normal system operation). These items are discussed in more detail in section 4.2.

3.7. Extreme Environmental Conditions

Special or unusual environmental conditions may present problems to either the filter system or operating personnel. Several conditions which must be considered during the design phase to preclude costly changes after the equipment is installed or contracted for are:

1. The type of environment in which the filter system will operate. Specific design features and requirements may vary depending on the climate, such as cold/wet, hot/wet, cold/dry, or hot/dry, and altitude.

2. Aging and weathering of components. Materials of constructions should be selected or treated to resist the corrosion and degradation that could result in loss of performance when exposed to specific environmental conditions.

3. Temperature and humidity. Gages and other instrumentation and equipment should be designed or selected to withstand the temperature extremes anticipated at the specific site. Temperature and humidity, unless extreme, do not normally appreciably degrade particulate filters. Prolonged exposure can degrade the adsorbent with respect to certain chemical agents primarily removed by chemisorption (i.e., by impregnated adsorbents). Physically adsorbed agents (e.g., those removed by activated carbon) are affected to a lesser extent.

4. Unusual circumstances or occurrences in the operating area. For example, painting or cleaning which may release solvents that could "poison" the activated carbon of the adsorbers, decreasing its life or capacity.

Intake openings for outside air should be equipped with louvers, grills, screens, roughing filters, or similar protective devices to minimize the effects of high winds, rain, snow, ice, trash, and other undesirable items that could be detrimental to the operation of the filter system.

4. DETAILED DESIGN CONSIDERATIONS

The equipment of a chemical-demilitarization air-cleaning system may be divided into two basic functions - filtration and ventilation. Filtration equipment includes, but is not limited to, the structure for housing the air-filtration components (particulate and gas adsorber types) and the blower unit. On the other hand, ventilation equipment includes, but is not limited to, the ductwork, dampers, hoods, and ventilation enclosures. This section discusses these two basic functions and provides information to be considered in their detailed designs.

4.1. Filtration System

4.1.1. Configuration

4.1.1.1. Basic Housings

There are two basic configurations considered for housing the filtration system: (1) housing with external blower unit, and (2) housing with internal blower unit. Both types are illustrated in figure 4-1.

4.1.1.1.1. Housing with External Blower Unit

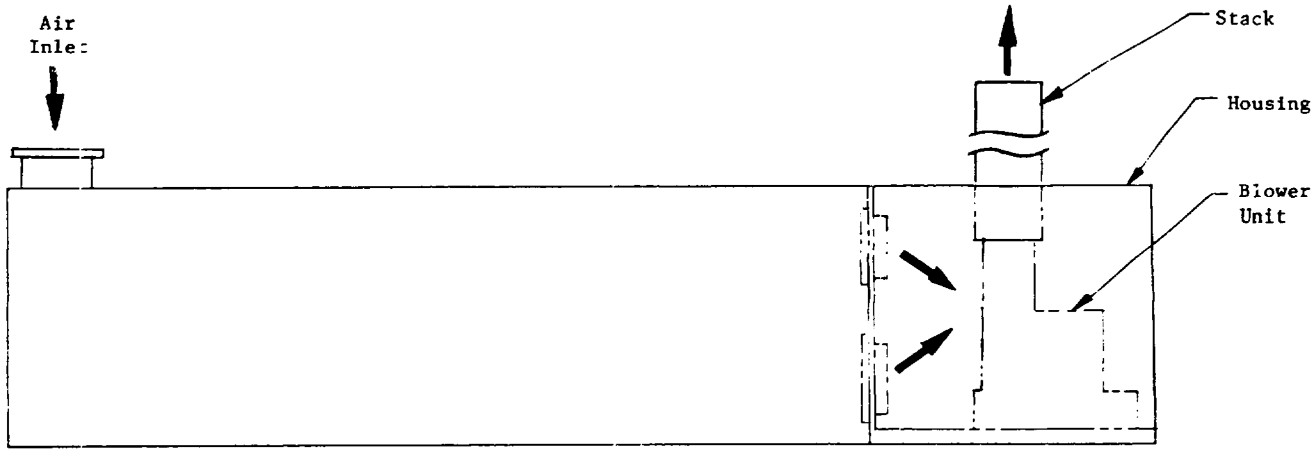
In this configuration the blower unit is located outside, downstream of the housing structure. It is connected to the housing by a tapered transition piece and short section of ductwork. The major advantages of this configuration are: (1) it reduces the housing size, and (2) it increases accessibility to the blower unit for maintenance and repair.

Transitions of such housings must be contoured to match the airflow in order to avoid cavitation and inefficient fan operation, and to ensure proper airflow distribution through the filters and adsorbers within the housing.

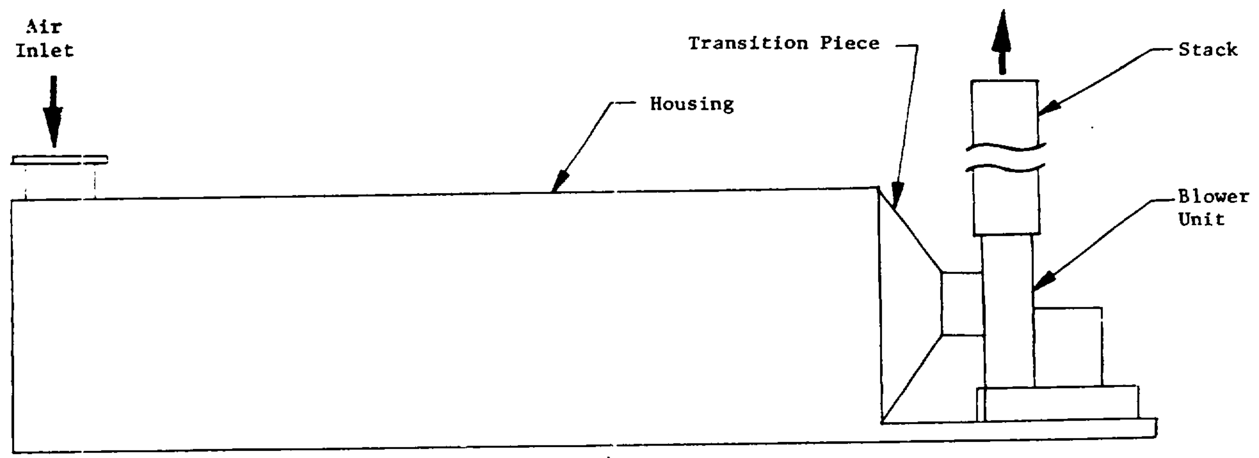
4.1.1.1.2. Housing with Internal Blower Unit

Here the blower unit is enclosed entirely inside the housing directly downstream of the filter/adsorber sections. The main advantage to this configuration is that the blower unit is protected from the weather. On the other hand, it offers a disadvantage in that fan entry pressure loss is greater than for a housing with a properly designed transition piece.

In selecting the basic housing design for CAMDS, the advantage offered by the internal-blower configuration superseded those of the external-blower concept because all the CAMDS filter units were to be located outdoors. Therefore, it was decided to house all blowers



a. Filter Housing with Internal Blower Unit



b. Filter Housing with External Blower Unit

Figure 4-1. Basic Filter Housing Configurations

completely indoors. The orientation of the fan inlet, however, depends upon the type of housing involved. In one type of housing,* the inlet end of the blower faces forward toward the filter/adsorber banks (see figure 4-2). This enables the drive belts mounted on the blower to be more easily observed through the inspection hatch on the rear of the housing. (See figures 4-3, 4-4, and 4-5.)

In another type of housing,** where there is already sufficient access to the blower, the fan inlet is reversed to face rearward (see figure 4-6a). The distance between the inlet and rear wall should be at least one blade-wheel diameter (i.e., tip-to-tip blade length of fan). This arrangement produces a baffling effect, which results in more uniform airflow from the final filter bank to the blower, thereby increasing fan efficiency. This configuration is particularly beneficial to the larger capacity systems. If the fan inlet faced forward, this would cause channeling of the air through the final filter bank, shortening its life and also causing very inefficient fan operation. (See figure 4-6b).

4.1.1.2. Filter Housings

Based on the changeout method employed and the type of adsorber cell used, filter housings may be divided into three basic types:

1. Type I - Bag-In Bag-Out, or Bag-Out only.
2. Type II - Walk-In, Multiple Adsorbers
3. Type III - Walk-In, Single Stationary Adsorber

A discussion of each type follows.

4.1.1.2.1. Type I Design (Bag-In Bag-Out or Bag-Out Only), Figures 4-7 through 4-11.

The type I housing, through the use of plastic bagging materials, permits filters and adsorber cells to be installed in or removed from contaminated enclosures without exposing the contamination to the atmosphere. (See section 6.4.) The major advantage of this configuration is that operating personnel, when changing filters or adsorber cells, do not have to work in a contaminated atmosphere nor wear as much protective clothing.

*This is the type I housing described in section 4.1.1.2.1.
**This is the type II housing described in section 4.1.1.2.2.

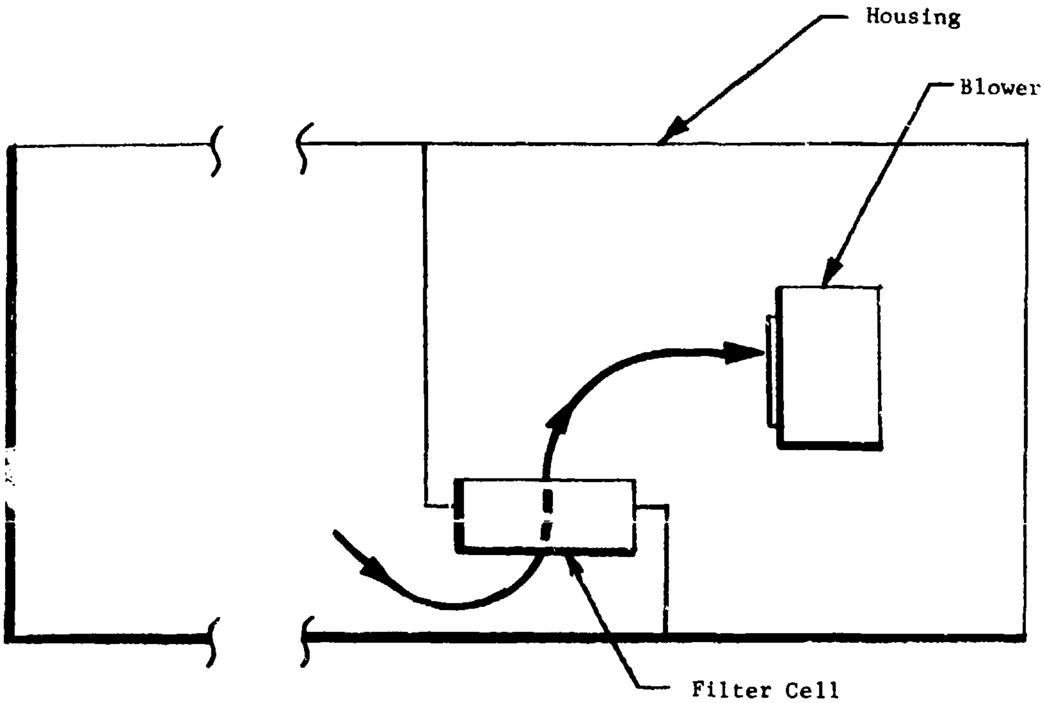


Figure 4-2. Blower Arrangement In Type I Housing. Fan Faces Forward Toward Filter Cell

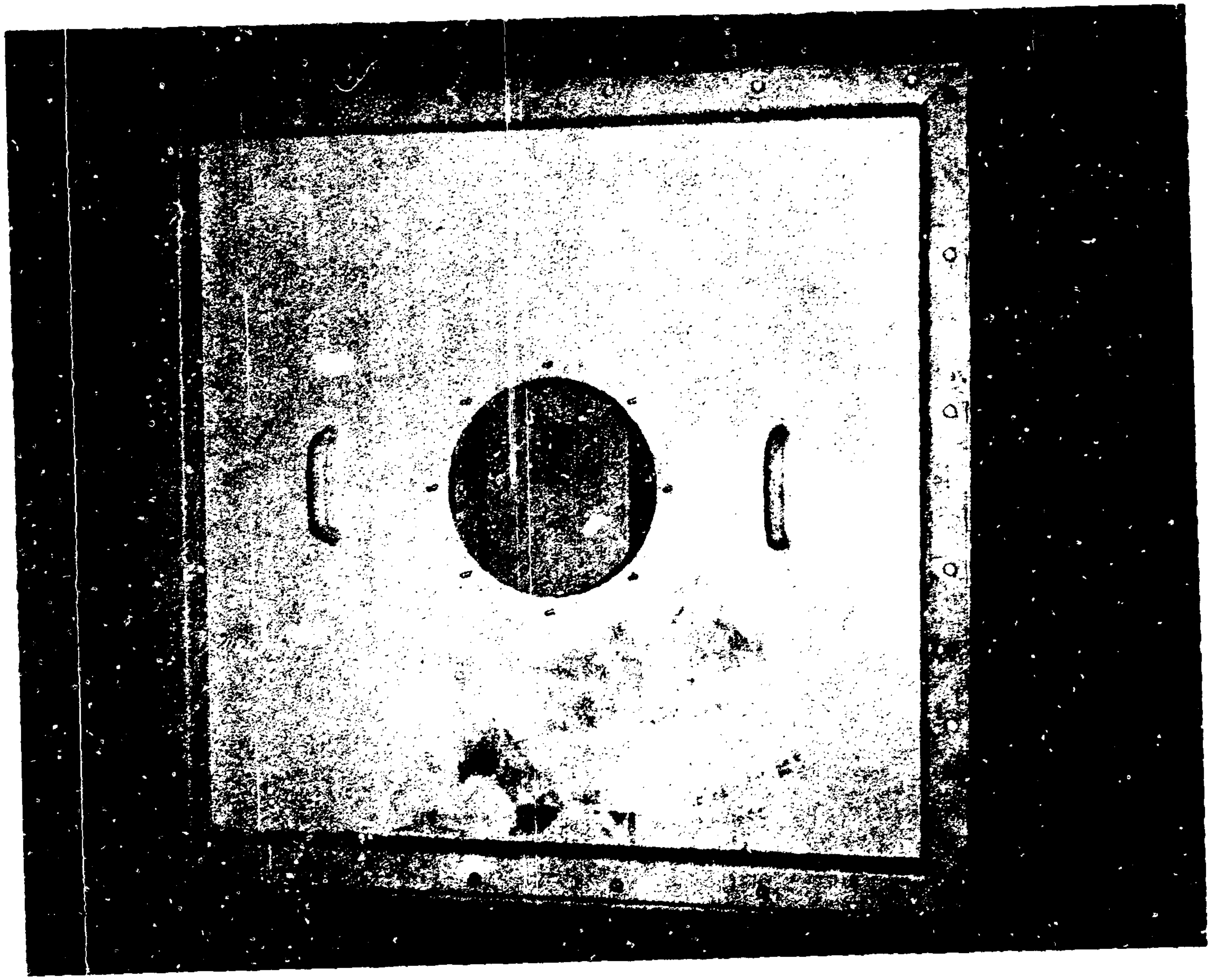


Figure 4-3. Blower In Type I Housing As Seen Through Rear Inspection Hatch With Plate Removed

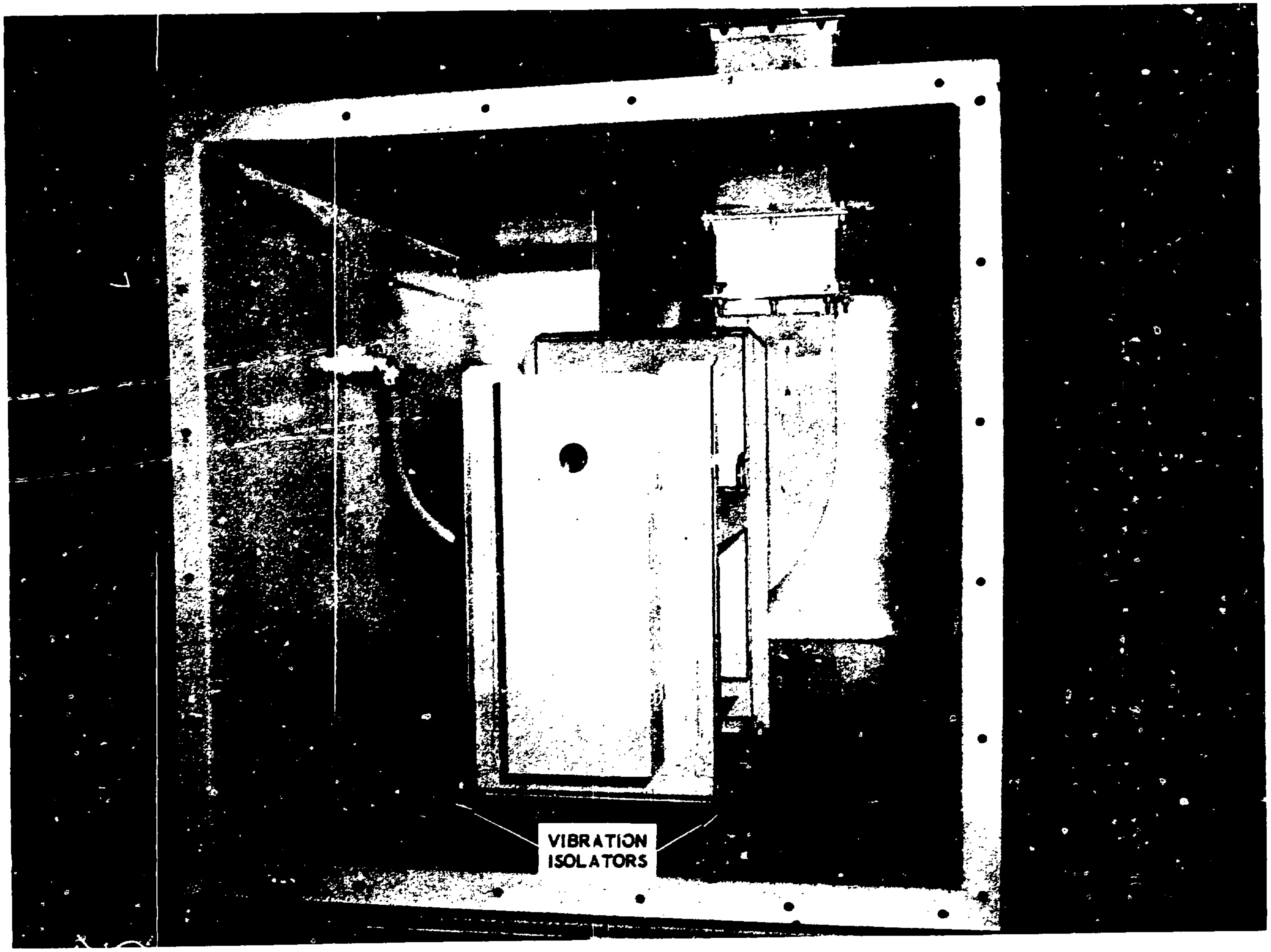


Figure 4-4. Blower In Type I Housing With Rear Maintenance Panel Removed. Power Cord Is Only Penetration In This Area On Smaller Units (Under 1,000 Cfm)

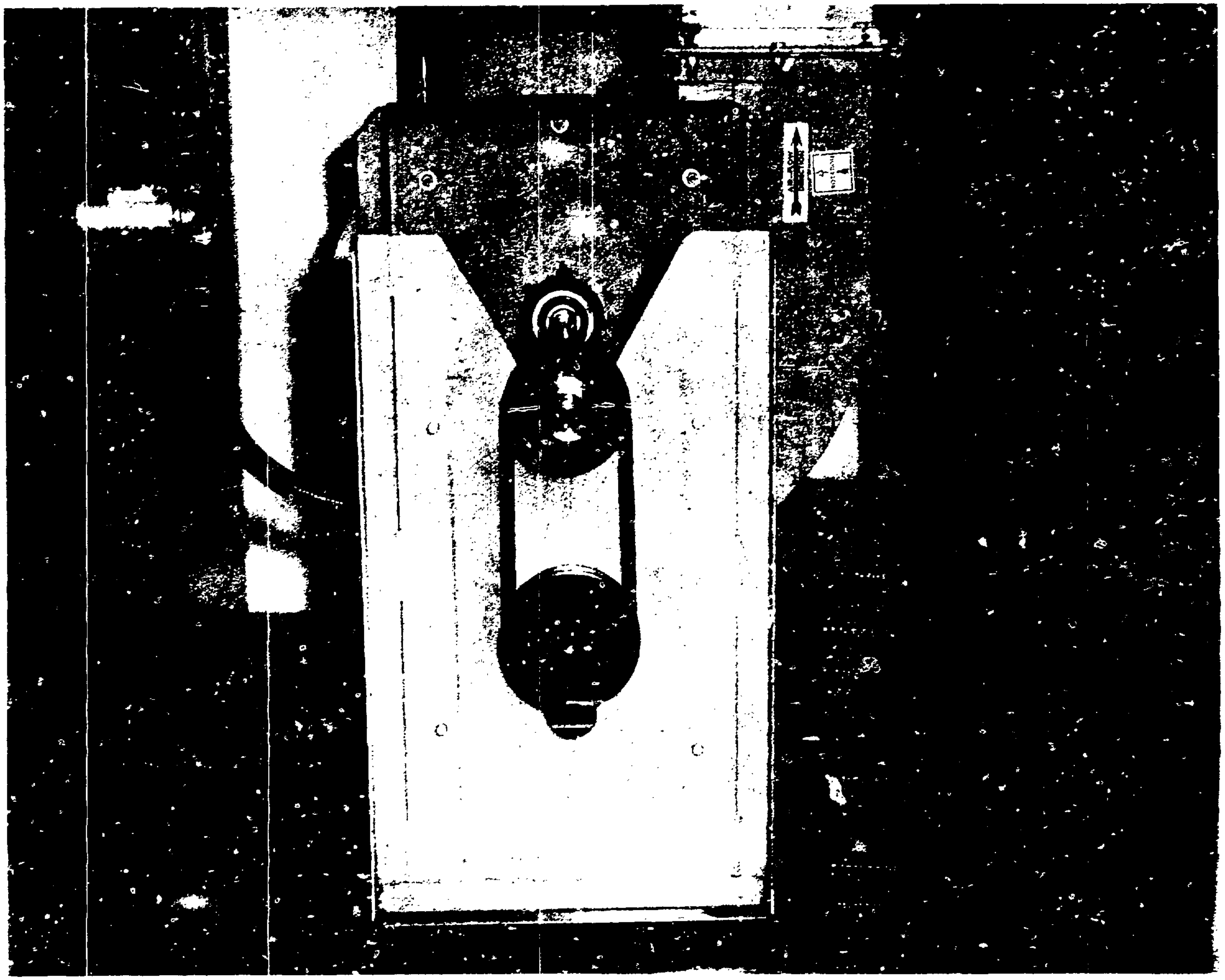
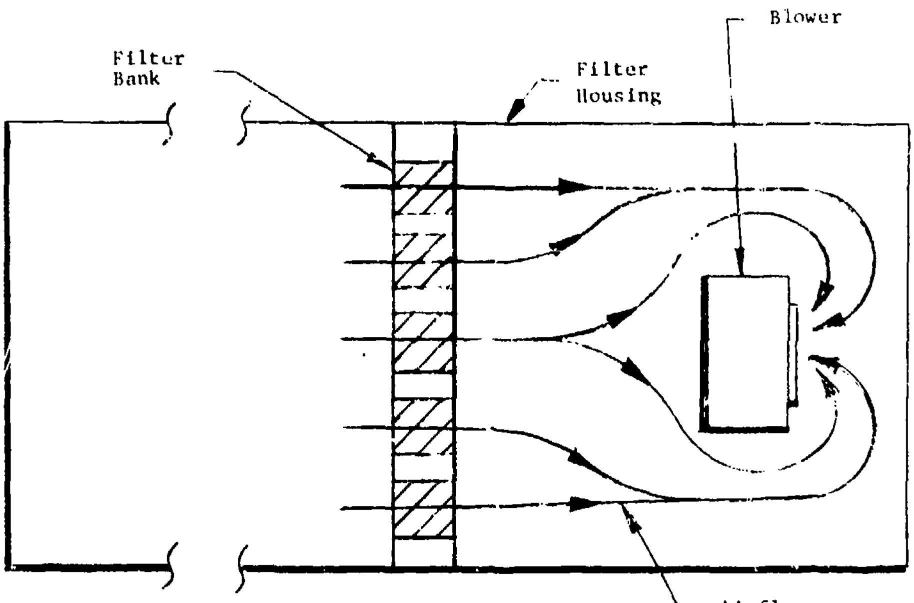
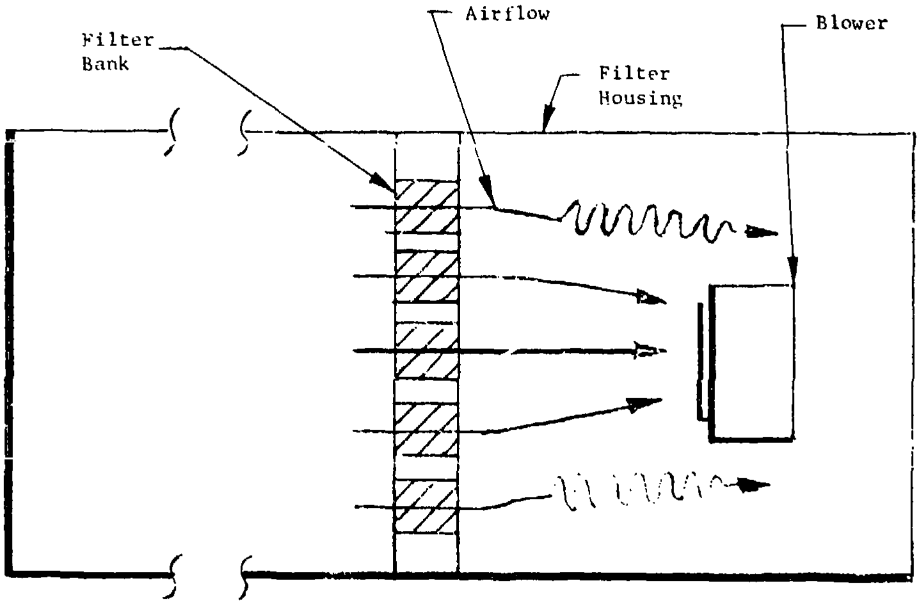


Figure 4-5. Blower In Type I Housing With Rear Maintenance Panel And Belt Guard Removed. Note Easy Access To Belt.



a. Fan Faces Rearward Away From Filters



b. Fan Faces Forward Toward Filters

Figure 4-6. Blower Arrangements In Type II Housing.

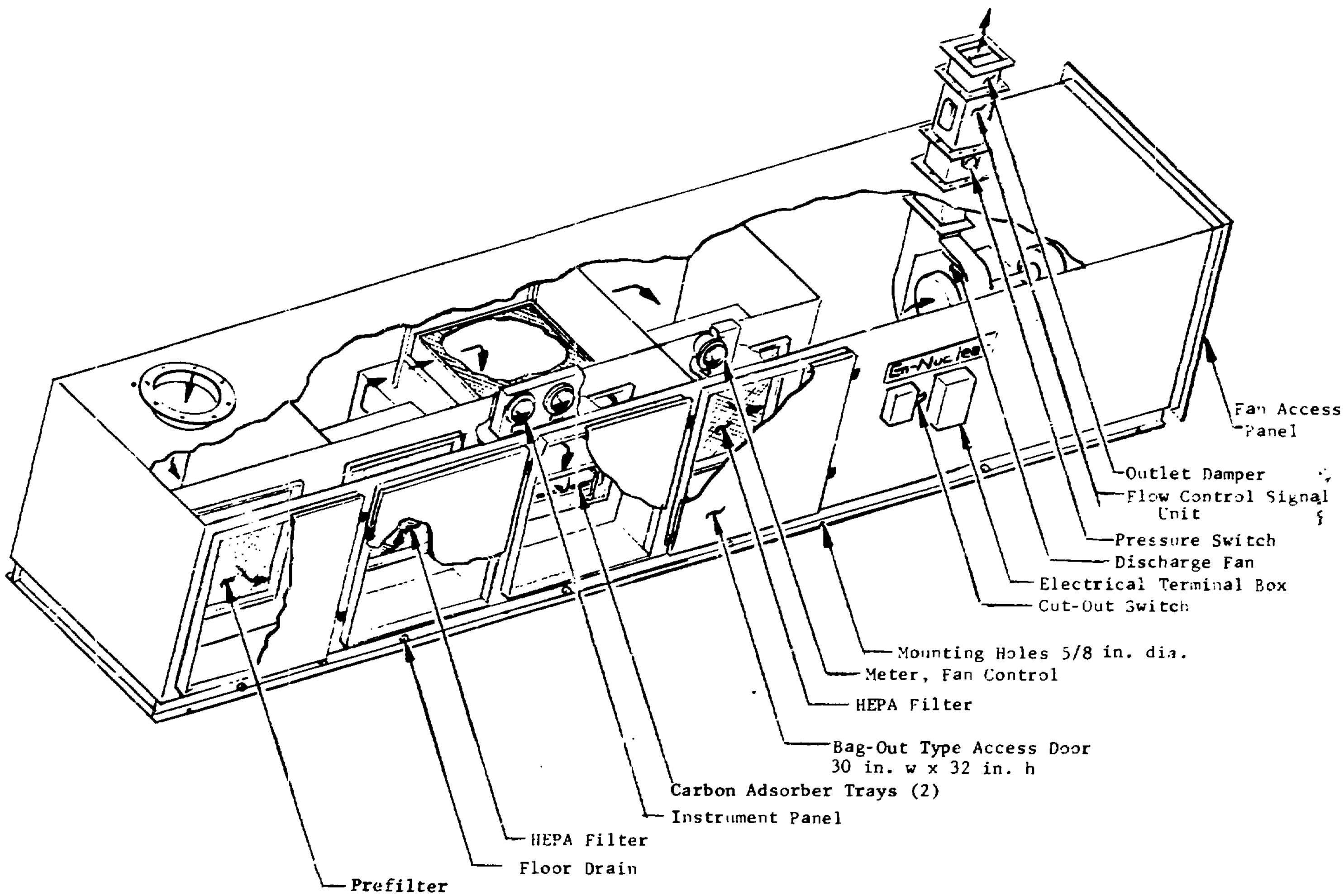


Figure 4-7. Type I Filter System (333 Cfm), Bag-In, Bag-Out or Bag-Out Only

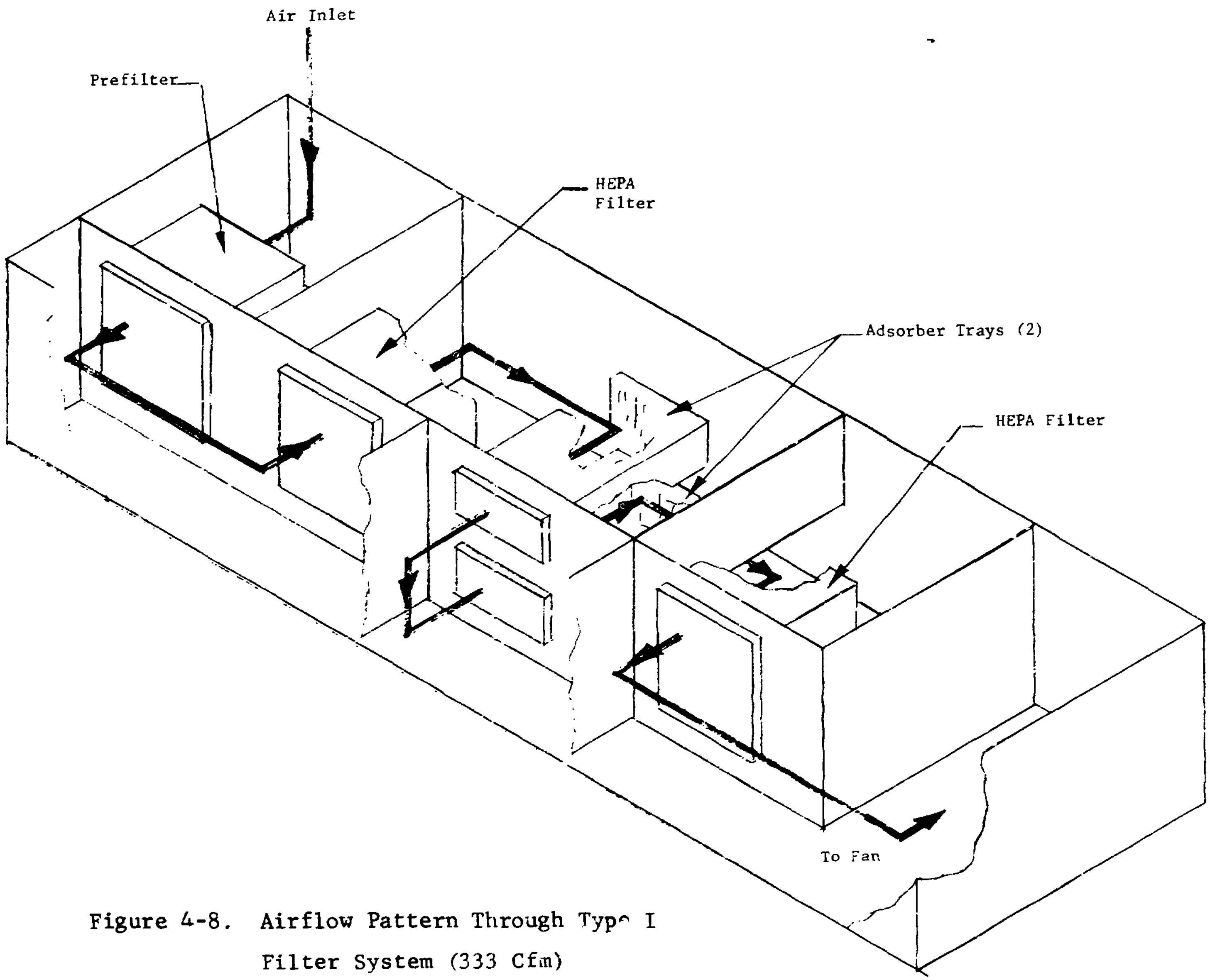


Figure 4-8. Airflow Pattern Through Type I Filter System (333 Cfm)

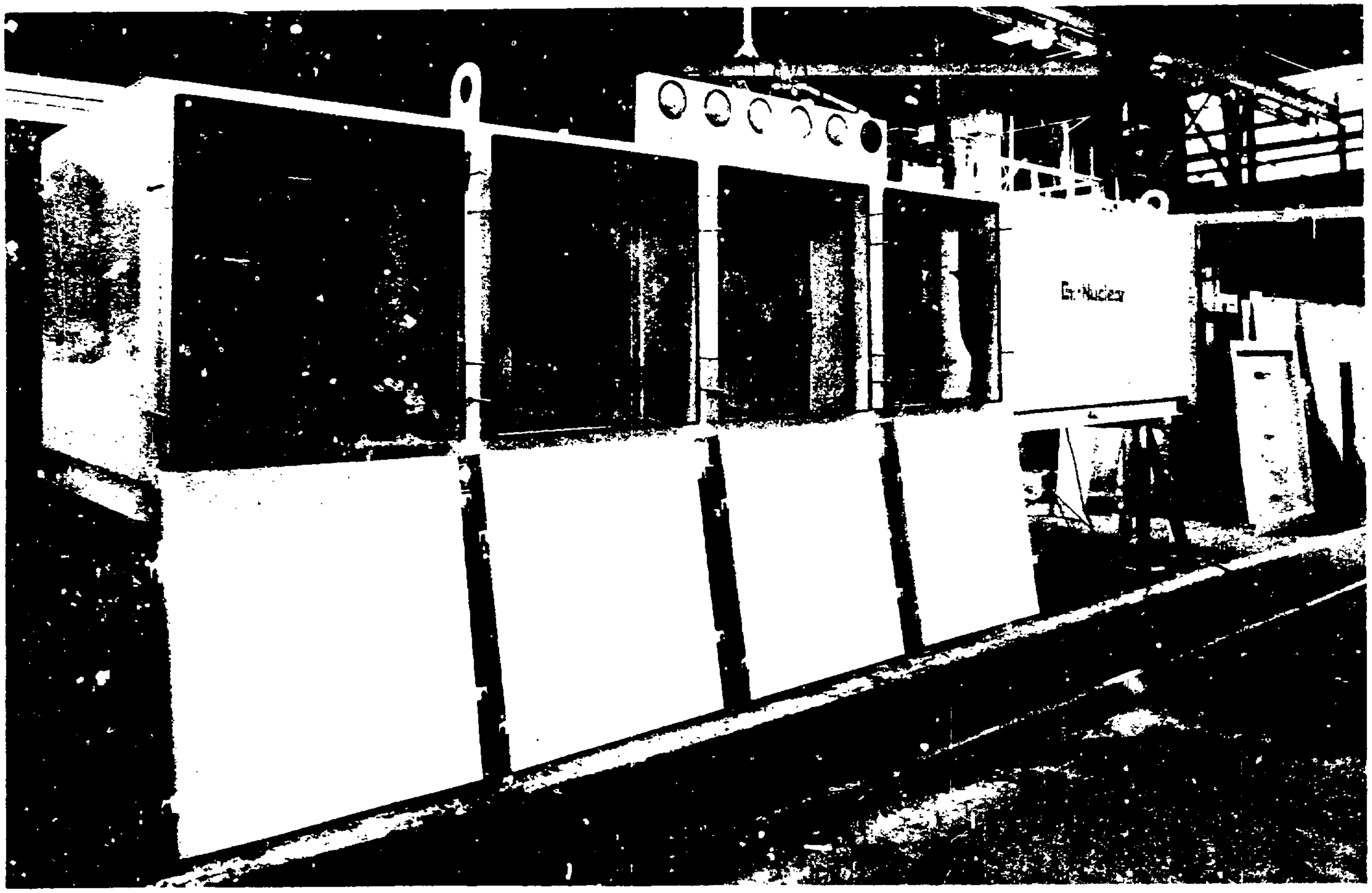


Figure 4-9. Type I Filter System (333 Cfm) With Access Doors Removed (Courtesy Of CTI-Nuclear, Inc.)

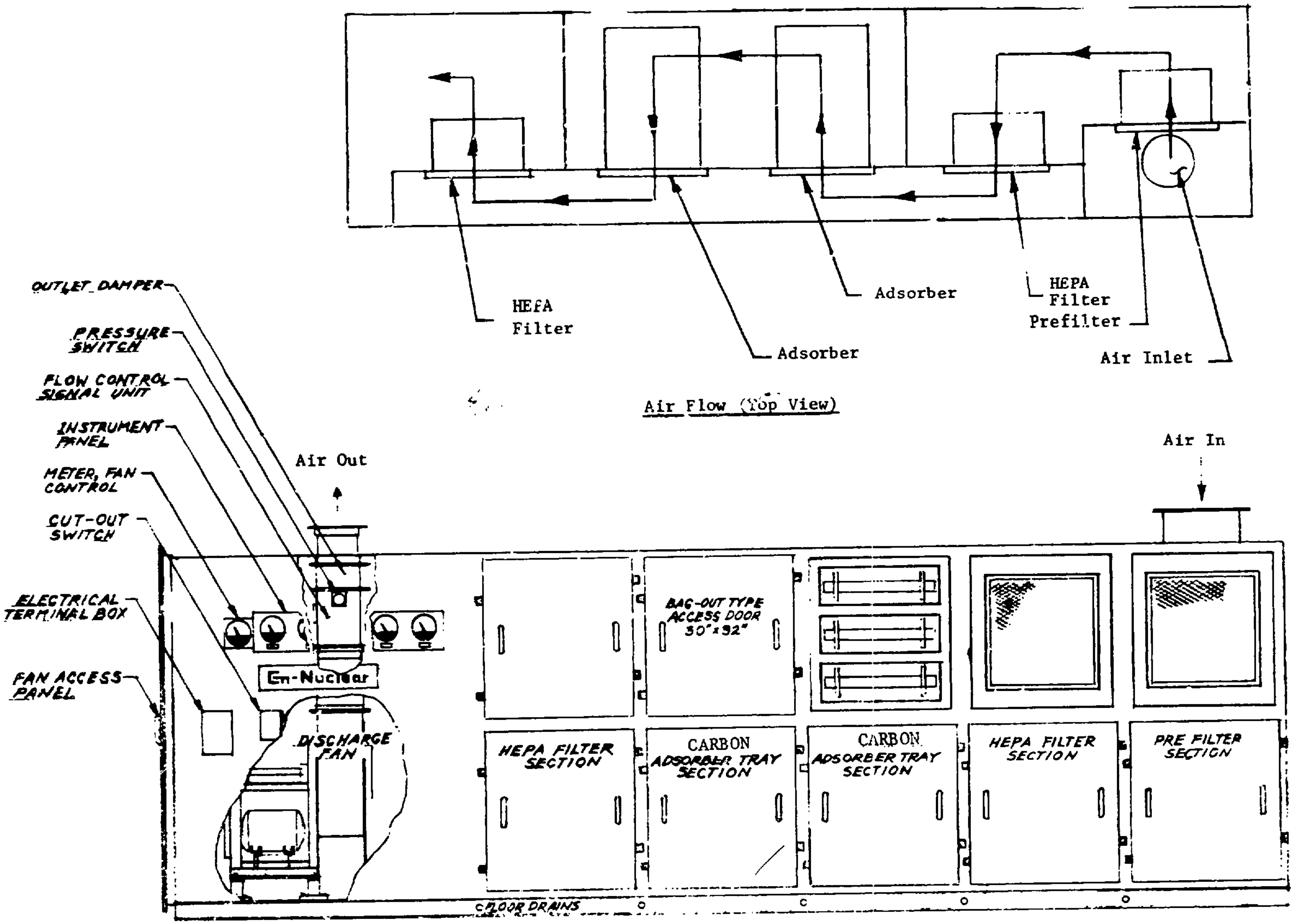


Figure 4-10. Type I Filter System (2,000 Cfm)
(Courtesy Of CTI-Nuclear, Inc.)

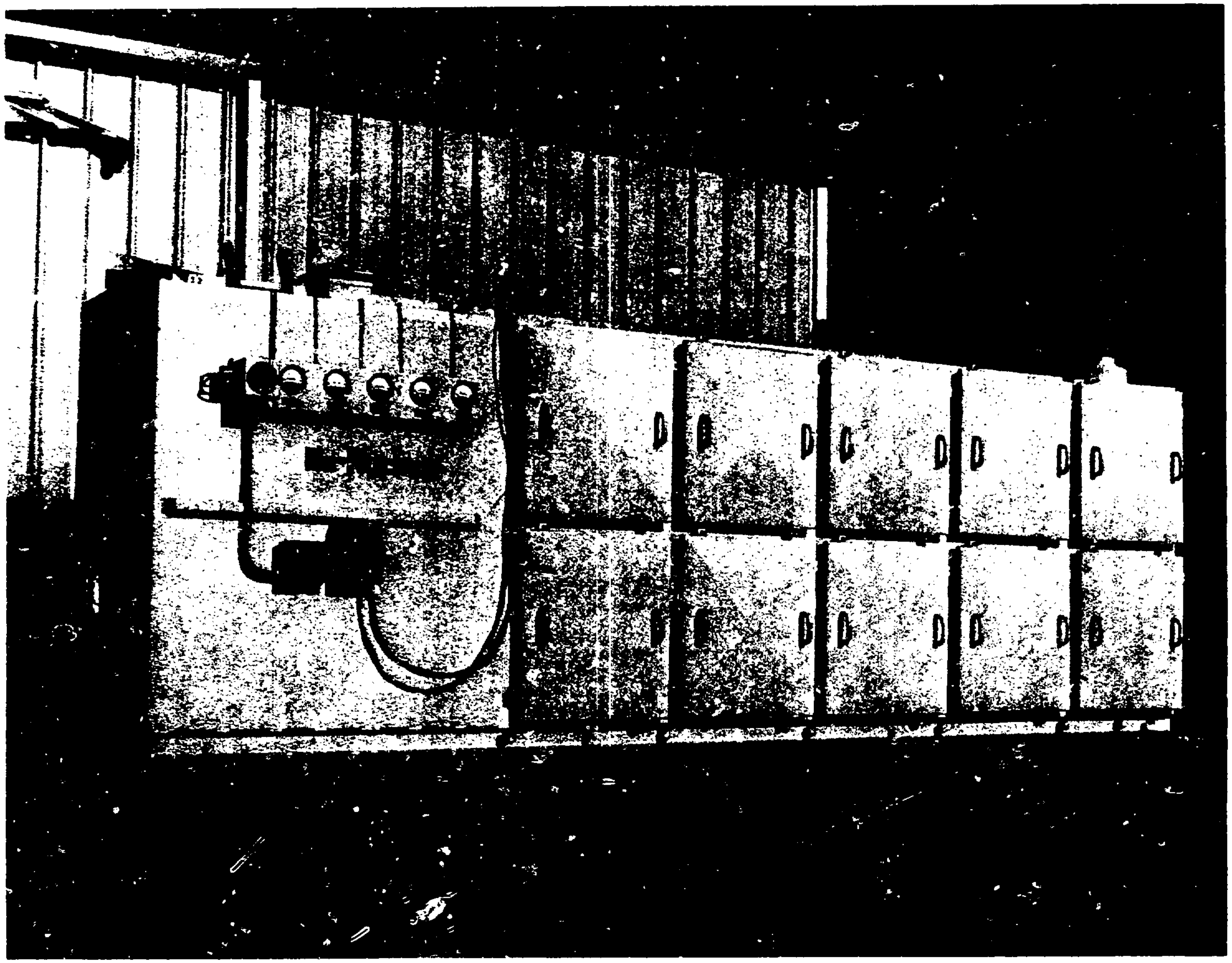


Figure 4-11. Type I Filter System (2,000 Cfm) On Concrete Pad At CAMDS Site Prior to Installation Of Ductwork And Exhaust Stack

Two disadvantages with the type I design, however, concern (1) the rate at which the cells are changed out, and (2) the space requirements. Since cell changeout takes place by reaching into the housing through a plastic bag, this tends to slow down the procedure and consume more time than with the other designs. It is essential that each cell be accessible to the outside so that changeout personnel can easily reach in and pull it out. This means that the cells must be consecutively arranged facing outward along the length of the housing rather than in parallel rows (or banks) as in the walk-in units, thereby significantly increasing the size of the housing.

For CAMDS the type I concept was particularly appealing because it eliminates the need for personnel to enter contaminated or potentially contaminated areas. However, in view of space limitations, it was determined that a 2,000-cfm flow rate was the maximum filter size that the type I design could effectively accommodate.

4 1.1.2.2. Type II Design (Walk-In Housing, Multiple Adsorbers), Figures 4-12 and 4-13.

The type II design, as its name implies, requires that protected personnel walk inside the filter housing to change the various cells. The chief advantage of this configuration is that it is more compact and economical at the higher capacities in that it permits a large number of cells to be efficiently installed in parallel and thus occupy significantly less space than with the type I design. Its major disadvantage is that personnel must wear protective clothing and must enter a contaminated or potentially contaminated area to perform changeout operations.

4.1.1.2.3. Type III Design (Walk-In Housing, Single Stationary Adsorber), Figure 4-14.

The difference between the type II and type III adsorber designs is that the former involves installation/removal of the entire adsorber tray (including metal parts, gasket, and adsorbent) while the latter involves installation/removal of the adsorbent only since the tray is fixed in place. The fabrication cost of a type II unit is less than for a comparable (i.e., in terms of capacity and bed depth) type III unit, although, as the number of trays in the type II unit increases, the difference in assembled cost decreases.

The major advantage of the type III housing over the type II design is that personnel do not have to enter the contaminated interior of the type III unit to change the adsorbent since this can be done remotely. A secondary factor to consider in comparing the two housing designs is the cost of adsorbent replacement. The more frequently the adsorbent is replaced the more advantageous the type III configuration becomes, as it is cheaper to replace adsorbent only rather than a complete assembly of relatively expensive metal parts. From the labor

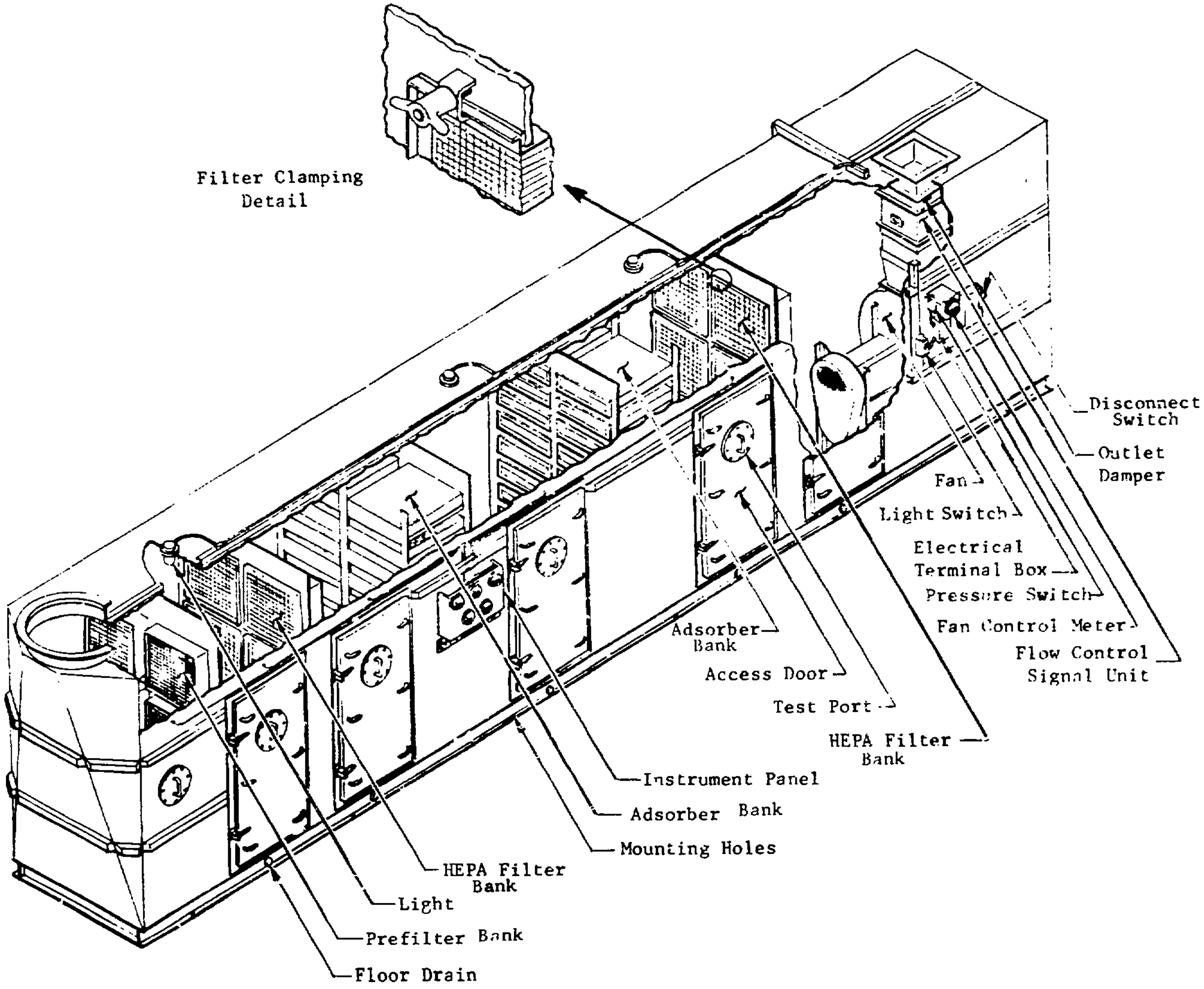


Figure 4-12. Type II Filter System (6,000 Cfm), Walk-In (Courtesy Of CTI-Nuclear, Inc.)

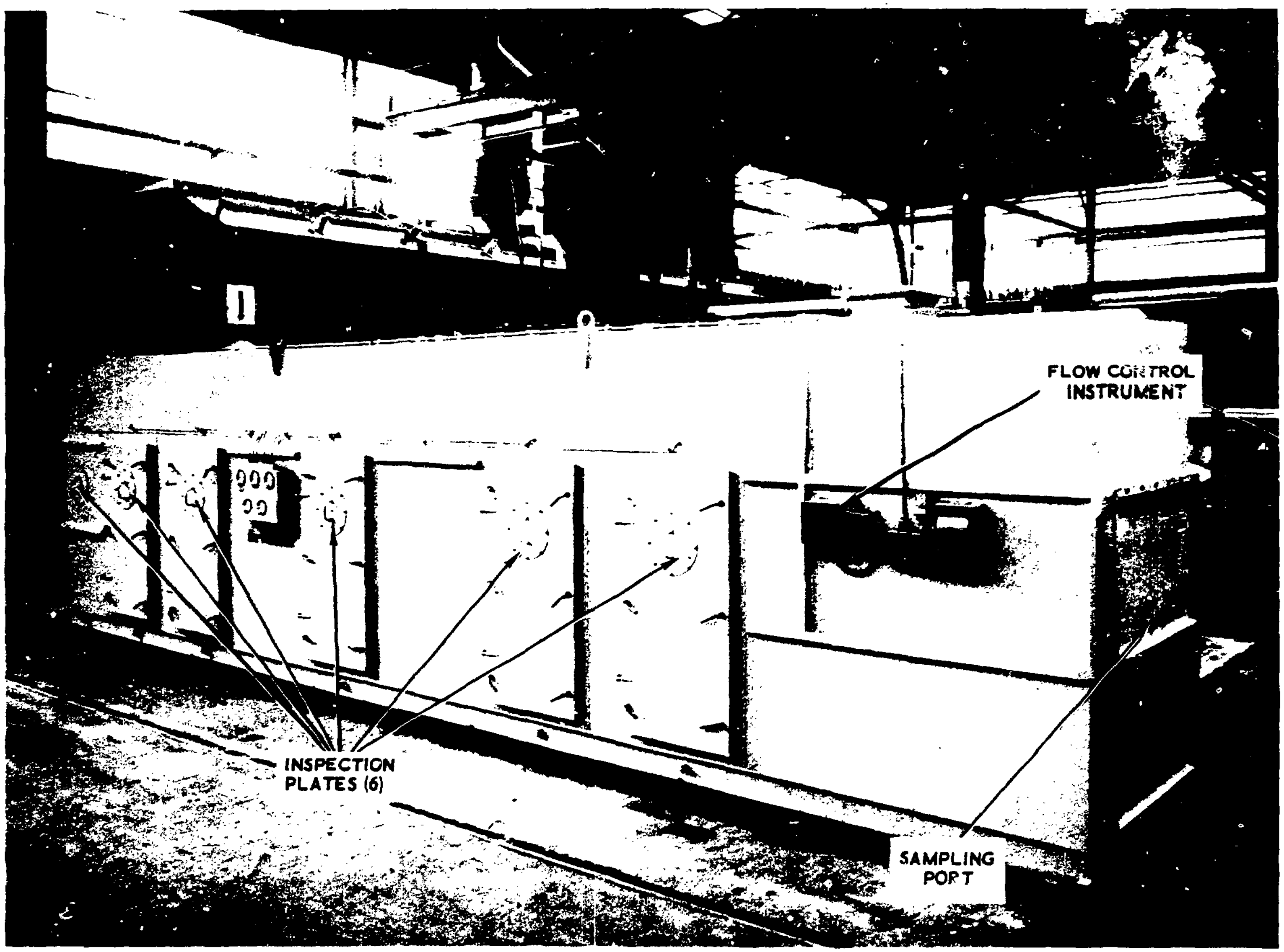


Figure 4-13. Type II Filter System (6,000 Cfm)
(Courtesy of CTI-Nuclear, Inc.)

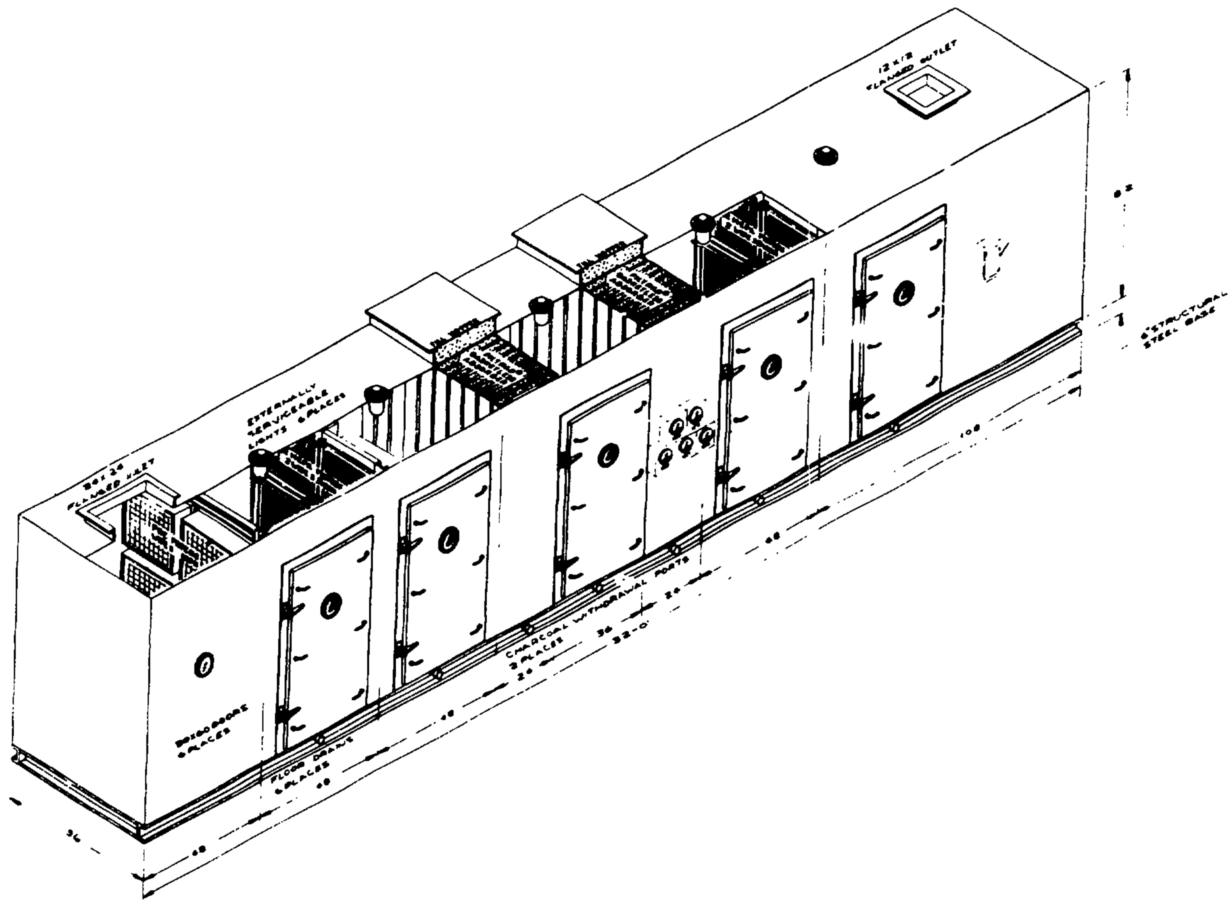


Figure 4-14. Type III Filter System (6,000 Cfm), Stationary Adsorber Walk-In Unit (Courtesy Of CTI-Nuclear, Inc.)

standpoint, emptying and filling permanently installed beds is considerably more economical and easier than struggling with 80-to 100-pound adsorber trays.

There are, however, several potential disadvantages to the type III design, namely:

1. This is a new concept that has been used for only a short period of time. It has never been tested or used in demilitarization work and thus may require extensive testing before being approved for use in this application.

2. Difficulty may arise in removing the adsorbent if a significant quantity of moisture has been adsorbed.

3. There are no applicable standards currently available for writing a specification. However, an ASME committee is preparing a standard establishing requirements for the stationary adsorber for publication at a later date.

4.1.1.2.4. CAMDS Filter Systems

At CAMDS there is a total of 13 filter systems, 12 at the CAMDS site and one at the chemical laboratory (which is located outside of the actual CAMDS compound). Important characteristics of these filter systems are shown in table IV-1. Their locations (except for the laboratory) are shown in figure 4-15.

4.1.1.3. Internal Configuration

4.1.1.3.1. Arrangement

If both filters and adsorbers are employed, one stage of particulate filter (or filters) must be positioned upstream of the first adsorber bank. These filters remove dust and particulate matter from the airstream, while the adsorber captures agent vapors generated in the facility or desorbed from the particulate matter collected on the filters. The reverse arrangement, i.e., adsorbers upstream of particulate filter, would not afford the same protection since the adsorber only stops vapors and not aerosols; the aerosols would pass through the adsorber and be stopped by the particulate filter where they could conceivably produce toxic vapors capable of escaping to the environment. In addition, the adsorbers would tend to plug up with dust.

Series-redundancy is an arrangement criterion whereby two filters of each type (i.e., particulate and gas) are required. Since, for most demil applications, both a particulate aerosol and vapor capability are mandatory, the arrangement for such filter systems is: (1) particulate filter (including prefilter), (2) adsorber, (3) adsorber, and (4) particulate filter. This arrangement is used for all CAMDS filter systems.

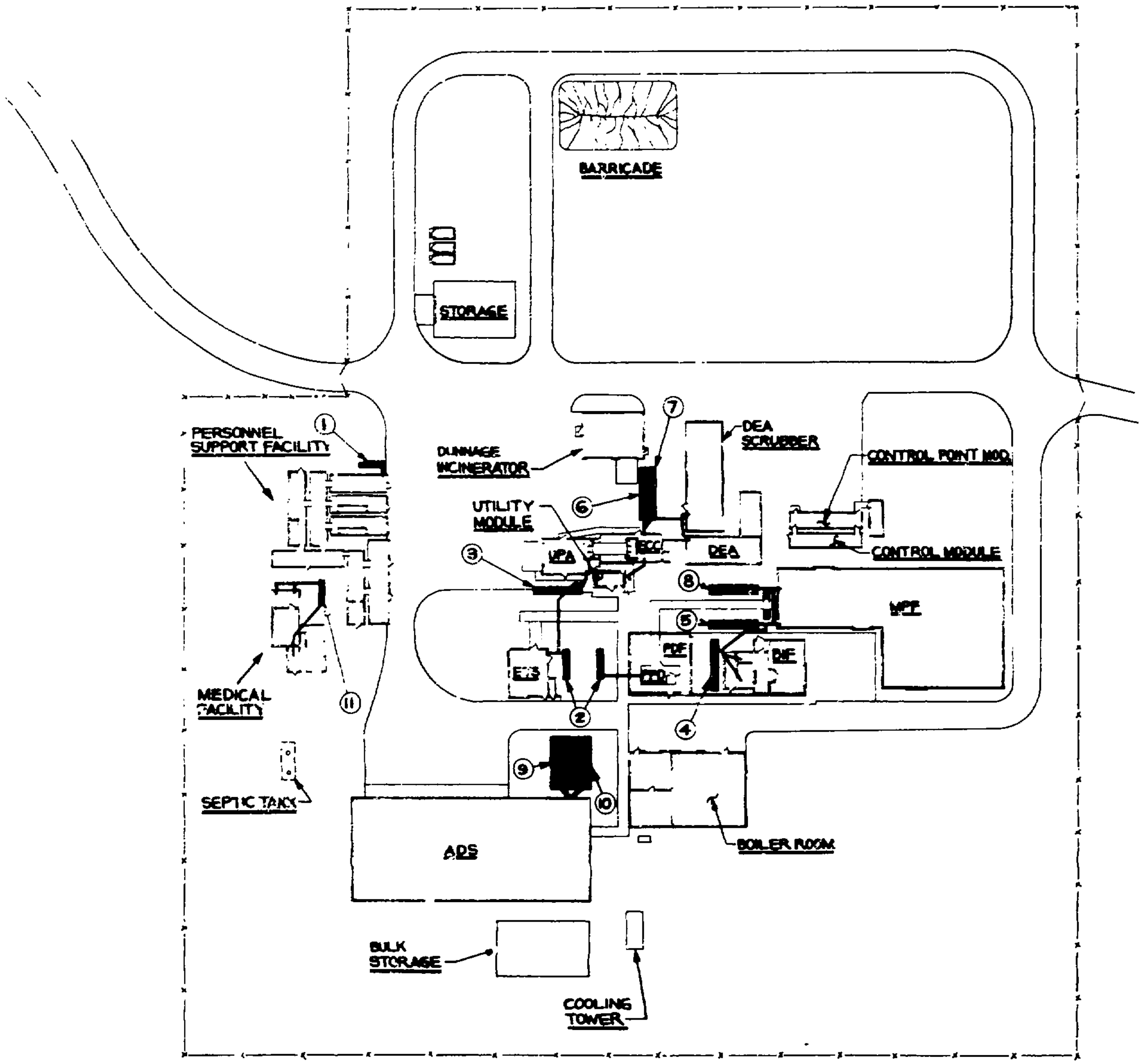


Figure 4-15. CAMDS Filter System Layout

Table IV-1.

Basic Data For CAMDS Filter Systems

Filter System				Filter Housing Dimensions			Approx. Housing Weight (lbs.)	Fan Data					Redundant Units By Number
No.[a]	Location	Capcaity (cfm)	Access Side (b)	Length (in.)	Width (in.)	Height (in.)		Motor On Emergency Power	Motor Rating (volts)	Motor Horsepower	Inlet Diameter (inches)	Outlet Opening (inches)	
1	PSC	333	Right	213	46	43	3,700	No	200	2	12	6 x 6	None
2A	ETS	2,000	Left	237	46	83	5,600	No	200	10	16	8 x 10	3
2B	PPD	2,000	Left	237	46	83	5,600	Yes	200	10	16	8 x 10	8(c)
3	UPA	3,000	Left	423	64	108	15,500	Yes	200	10	20	10 x 12	2A or 6(c)
4	BIF	5,000	Right	423	64	108	15,500	Yes	200	10	20	10 x 12	5 or 8
5	MPF	4,000	Right	423	64	108	15,500	Yes	200	15	22	12 x 14	4 or 8
6	ECC	6,000	Left	423	64	108	15,500	Yes	200	20	23	14 x 16	7
7	DFS	6,000	Right	423	64	108	15,500	No	200	20	28	14 x 16	6
8	PDF (Output)	8,000	Right	429	91	108	20,000	Yes	200	25	32	16 x 18	5 or 4
9	ADS North	15,000	Left	435	144	108	30,500	Yes(d)	460	40	44	22 x 26	10
10	ADS South	15,000	Right	435	144	108	30,500	No(d)	460	40	14	22 x 26	9
11	Med. Mod.	2,000	Left	237	46	83	5,600	No	200	10	16	8 x 10	None

Notes

(a) Numbers refer to filter systems depicted in figure 4-15.

(b) When facing in same direction as airflow. (Filter housing can be designed to have access on either side.)

(c) These filters pull on designated locations directly through interior of buildings by adjusting some interior damper or ducts, not by adjustment of dampers in ductwork.

(d) Either Filter No. 9 or 10 may be on emergency power. Interlocking switching allows selection of either unit.

4.1.1.3.2. Sizing

Using a modular concept, the filter system could conceivably be any size desired. However, there are certain limitations which apply to the individual modules. Generally, the size limit is based on space availability and the ability to (1) test the filters and adsorbers, (2) provide uniform airflow, and (3) manage system upsets. Because of the requirement for external access to every cell, the type I housing requires more space per cfm than the other two designs. The maximum capacity recommended for a type II or III structure, to keep it from becoming too huge, is 30,000 cfm.[7] If, on the other hand, transportability is a design consideration, the dimensions of the unit must be such that it can be handled by truck or rail. This results in a recommended maximum size of 15,000 cfm for type II or type III housings.

For the type II or type III units, as previously indicated, the filter/adsorber banks are arranged to facilitate changeout. Each bank should be no more than three units high to permit the top bank to be within reasonable reach. (Note: Three adsorber cells occupy the same vertical space as one 1,000-cfm HEPA filter.) Recommended standard housing capacities are 3,000, 6,000, 9,000, 12,000 and 15,000 cfm. If the desired capacity is not one of these ratings, it is recommended that the installed capacity be sized up to the next standard size and that unused cell openings be closed off with blankoff plates. Oversizing does not significantly increase the price of the system since a standard unit is still being used, as opposed to the price of a customized design for a specific, non-standard capacity. Another advantage of the oversized unit is that, by installing a larger blower and placing filters/adsorbers in the closed-off sections, filter-system capacity can be increased later at minimal cost should the need arise.

At CAMDS the maximum agent challenge expected to be encountered in any area was initially estimated at 10,000 mg/m^3, based on a saturated solution of GB at 70^{o}F. This indicated the need for a filter system providing a reduction capability on the order of 10^8, that is:

$$\frac{\text{Concentration out}}{\text{Concentration in}} = \frac{C_o}{C_i} = \frac{3 \times 10^{-4}}{1 \times 10^{4}} = 3 \times 10^{-8} \text{ reduction}$$

With a minimum protection time of 20 minutes (before decontamination), the minimum capacity of the required filter system (i.e., maximum challenge concentration x time to decon) is:

$$10{,}000 \ \frac{\text{mg}}{\text{m}^3} \times 20 \text{ min.} = 200{,}000 \ \frac{\text{mg-min}}{\text{m}^3}.$$

To meet this requirement, two banks of adsorbers with a demonstratable reduction ratio of 1.5×10^{-4} each (i.e., 3×10^{-8} reduction divided between the two banks) were procured for each area, with each bank providing an adsorptive capacity of 200,000 $\frac{\text{mg-min}}{3}$. (See section 7 for testing techniques.)

Subsequent to the procurement and installation of these filter systems, and in view of greater experience with the CAMDS operations, a more detailed study was conducted of the probable maximum agent challenge.[13] It was determined that this could result from a major spill in the BIF area and potentially result in an agent concentration of 300 mg/m^3 in the influent air stream of the BIF. This value, which is felt to be more accurate and realistic than the initial estimate, is considerably lower and indicates a reduction requirement on the order of 10^6, that is:

$$\frac{C_o}{C_i} = \frac{3 \times 10^{-4}}{3 \times 10^{2}} = 10^{-6}$$

The minimum capacity of the filter system then becomes:

$$300 \ \frac{\text{mg}}{\text{m}^3} \times 20 \text{ min.} = 6{,}000 \ \frac{\text{mg-min}}{\text{m}^3}$$

The CAMDS site uses three basic configurations - 6,000, 9,000, and 15,000 cfm. Intervening capacities (e.g., 3,000, 4,000, and 3,000 cfm) are sized up to the next higher standard ratings (in this case, 6,000 and 9,000 cfm). Table IV-2 itemizes the number of filters and adsorbers comprising each filter-system capacity at CAMDS. Although the same internal configuration applies to all housings with the same capacity rating, there are minor differences to accommodate the specific capacity involved. For example, the 3,000 4,000, and 6,000-cfm systems - all utilizing the 6,000 cfm housing - each has different size inlet openings, blowers, and exhaust stacks.

Table IV-2. Number of Filters and Adsorbers Comprising Each Type of Filter-System Capacity at CAMDS

Quantity of Filter Systems	Capacity (cfm)	Pre-Filters	No. 1 Bank HEPA Filters	No. 1 Bank Adsorbers	No. 2 Bank Adsorbers	No. 2 Bank HEPA Filters	Configuration
1	333	1	1	1	1	1	Type I
3	2,000	2	2	6	6	2	Type I
2	3,000	6	6	9	9	3	Type II (3h x 2w)
1	4,000	6	6	12	12	4	Same
2	6,000	6	6	18	18	6	Same
2[(a)]	8,000	9	9	24	24	8	Type II (3h x 3w)
2	15,000	15	15	45	45	15	Type II (3h x 5w)

(a) One of these units is used in the chemical laboratory, which is located outside the actual CAMDS compound.

Instead of blanking off unneeded cells on all five banks, an alternate procedure is to blankoff only the two adsorber banks and the second HEPA filter bank while operating all cells in the prefilter and first HEPA filter banks. The particulate cells in the first two banks are normally the most frequently changed elements in the filter system. The cost of these cells, however, is relatively inexpensive when compared to the labor expense for replacing them. Therefore, by using more cells than are actually needed, the flow through each cell will be less than the rated flow and the life of the cells will be extended, thereby reducing the number of changeouts required during the life of the system.

If the airflow through each cell is less than the manufacturer's rated capacity of the cell, then the ΔP is also reduced. This means that the initial ΔP of the bank is less and that more contamination can be retained before changeout is required. Actual readings, indicating these lower values, are shown in table IV-3. Since the frequency of changeout for the second HEPA filter is low, it may not be practical to install extra units in these locations. Extra adsorber cells also are not installed because of their high cost.

Table IV-3. Summary Of Differential Pressure Gage Readings At CAMDS Site 5-8 October 1976

Filter Location	Actual Capacity (cfm)	Differential Pressure Readings (in. wg)					
		Prefilter	First HEPA Filter	First Adsorber	Second Adsorber	Second HEPA Filter	Total
PSC	333	.09[b]	.25[b]	.62	.58	.28[b]	1.82
ETS	2,000	.20	.90	.55	.70	.98	3.33
PPD	2,000	.25	.82	.62	.62	.81	3.12
UPA	3,000	.09[a]	.40[a]	.64	.56	.84	2.53
BIF	3,000	.09[a]	.30[a]	.60	.52	.69	2.20
MPC	4,000	.18[a]	.43[a]	.61	.58	.89	2.74
ECC	6,000	.25	.82	.60	.55	.72	2.94
DEA	6,000	.38	.82	.52	.52	.72	2.96
PDF (Output)	8,000	.25[a]	.88[a]	.78	.78	1.00	3.69
ADS South	15,000	.38	1.05	.90	.78	.93	4.04
ADS North	15,000	.34	.92	.75	.71	.79	3.51

Notes:

(a) Indicates a bank where additional cells were installed instead of blankoff plates.

(b) Low readings in these filters were caused by less-than-rated airflows being pulled through the banks. Adsorber cells are rated at 333 cfm, while prefilters and HEPA filters are rated at 1,000 cfm.

4.1.1.3.3. Spacing

Although the actual length of a filter housing is normally determined by the manufacturer based on his overall design, the user may want to specify any or all of the following governing dimensions:

1. The minimum distance between banks in the type II and type III units to permit sufficient space for changeout. This value should represent the minimum width required by personnel in protective clothing (Level A) for passage plus the maximum depth of a typical modular cell (which must be completely removed from its mounting frame).

2. Minimum distance to prevent fire propagating from one bank of cells to another.

3. Maximum overall length available where housing is to be located.

At CAMDS the spacing between the prefilter and first HEPA filter bank is 40 in., 66 in. between the two adsorber banks, and 40 in. from the second adsorber bank to the second HEPA filter bank. This assumes maximum depths of 12 in. for the prefilters and HEPA filters and 30 in. for the adsorber cell. Since it was decided at CAMDS that ventilation would not continue in case of a fire, none of the special design features mentioned here for fire protection were included in its design.

Adequate spacing to perform basic maintenance on the blower assembly should also be provided. Since this is usually a clean area in which personnel do not need protective clothing, working space here is not necessarily critical. The location of the blower from the final filter bank to obtain proper airflow should be left to the discretion of the manufacturer. At CAMDS all spacing requirements with respect to the blower unit, instead of being specified, were left to the manufacturer.

4.1.1.3.4. Location

In determining the location of filter housings, all airflow and negative pressure requirements must be considered as well as various ways for routing the ductwork. The designer must keep in mind when locating filter housings that adequate adjacent space must be included for changeout and maintenance. Since the largest expense once a system has become operational is the labor involved in cell changeout, careful attention must be given to providing sufficient space for workers in protective clothing to move about. For type I units, in addition to access for changeout on the door side, clearance should be allowed for personnel to observe through the inspection ports on the backside (that is, the side away from the doors). Inspection ports on the backside of the type II and type III housings

are unnecessary, although some clearance should be provided there, as with the type I units, to enable personnel to attach the housing to its foundation during installation.

Unless specific safety criteria demand otherwise, it is recommended that a path at least five-feet wide be provided on the access side of the housing and at the rear near the blower unit. In addition, there should be sufficient access for a fork-lift truck to reach the housing to assist in the changeout operations. At CAMDS a five-foot clearance path is provided at all filter units. This space is shown in figure 4-15 surrounding both the rear and access sides of each housing. Access doors can be installed on either side of the filter housing depending on which side offers more space and greater convenience at the installation site.

Space considerations determine the actual location in demil applications. An indoor location in a ventilated area is generally preferred because it avoids most of the disadvantages associated with outdoor installation. Since it is unlikely in most demil cases that sufficient space will be available for complete indoor installation, the remainder of this discussion is limited to outdoor installation.

The major problems with an outdoor location are weathering and its detrimental effects and lack of secondary containment. (See section 3.7.) Equipment is exposed to heat, cold, rain, snow, sand, sun, and humidity. As a result, additional requirements are placed on materials, protective finishes, construction, and personnel to enable functioning and survival. If weather conditions become too severe, it may be necessary at times to provide temporary protective shelters during servicing.

Ground-level installation is recommended rather than on rooftops. Although a rooftop location may reduce duct length, its major disadvantages are: (1) it requires additional structural support, (2) it presents serious logistic problems in transporting cells and equipment during changeout and servicing, and (3) it creates an additional safety hazard for service personnel. At ground level, the housing should be situated on a concrete pad or other solid foundation to which it is securely fastened (e.g., by bolting). The housing must be installed level and at sufficient elevation to facilitate drainage and alignment of the ductwork.

All CAMDS filter housings are installed outdoors on concrete foundations. Although the facility is not yet completely operational various housings have been in place and operating on an intermittent basis for one to two years. None of the filter housings or ductwork show any signs of deterioration. The severe climate, however, has affected the instrumentation and changeout bags, requiring certain modifications to be made to correct these problems, as described later in section 4.1.2.12.5.

4.1.2. Filter Housing Details

4.1.2.1. Introduction

The filter housing provides a complete, airtight protective enclosure extending from air inlet to air outlet. It is essential that the filter components and mounting frames inside the housing form a continuous barrier between the contaminated zone and atmosphere. Any hole, crack, or defect in a mounting frame or seal between the filter components and frame may result in leakage.

Penetrations through the housing skin should be minimized for the following reasons: (1) inward flow of air into the housing will reduce flow from area to be filtered, (2) outside air may contain moisture, and (3) outward leakage of contamination may result. It is preferable to have all penetrations made by the manufacturer at his facility before the housing leak tests are performed. If penetrations are necessary after the housing has left the manufacturer, leaktight fittings must be used. Do not rely on sealants (e.g., RTV silicone) to stop leakage.

The CAMDS filter housings, depending on their size, contain one or two leaktight penetrations aside from sampling ports, inspection ports, and pressure taps. Type I units up to 1,000-cfm capacity contain one penetration only for the electric cable running between the cutoff switch, junction box, and motor. The larger units contain this penetration plus another one for the electric and signal lines for the flow-control system.

It is important that the following additional factors be considered in the design of the filter housing. These factors are discussed in the following sections and in Chapter 4 of reference 7.

1. Structural rigidity of mounting frames.

2. Rigid and positive clamping of components to mounting frames.

3. Strict adherence to close tolerances on alignment, flatness, and surface condition of component sealing surfaces.

4. Welded-frame construction and welded seal between mounting frame and housing.

5. Ability to inspect interface between components and mounting frame during installation.

6. Adequate door openings in walk-in units (type II and type III) to allow personnel in protective clothing to enter easily.

7. Elimination of sharp projections which could cause maintenance personnel to cut themselves or tear their protective clothing.

8. Adequate sampling ports for leak testing and agent monitoring.

To verify leaktightness and structural rigidity, the housings should be subjected to both a positive and negative pressure test and a negative-pressure decay test as described in section 2.1.3 of Appendix B and ANSI N510[8]. These tests were performed on each of the CAMDS filter housings at the manufacturer's plant after the units were completely assembled. The blower assembly was not included for some of the tests. A value of 24 in. wg was used since it represents twice the maximum ΔP at which the system is designed to operate.

4.1.2.2. Mounting Frames

Mounting frames, used to support the filters and adsorbers, are critical components of the filter housing. They must be stringently designed to provide adequate rigidity and to withstand shock loading without exceeding the elastic limits of the frame material. The frames should be of all-welded construction composed of carbon or stainless steel structural shapes, plates, or heavy cold-formed sheets. Carbon steel frames should be painted or coated for corrosion resistance. (See section 4.1.2.8.)

There are three basic types of mounting frame construction: (1) face-sealed, in which the filter seals to the outermost surfaces of the frame members by means of gaskets bonded to the front surface or to the flange around the face of the filter unit; (2) pocket, in which the filter fits into an opening of the frame and seals, by means of a gasket bonded to the face flange of the filter unit, on an inner flange; and (3) drawer, in which the filter (or adsorber cell) fits through an opening and seals, by means of a gasket bonded to the back of the face plate of the filter or adsorber cell, to the outermost surfaces of the frame members.

Filter mounting frames should be shop fabricated because it is nearly impossible to avoid misalignment, warping, and distortion in field fabrication. Shop fabrication is less costly than field fabrication and permits better control over assembly, welding, and dimensional tolerances. Care must be taken to avoid twisting or bending of the completed frame during handling, shipping, and field installation. For proper performance and ease of maintenance of installed filters, dimensional and surface-finish tolerances must be tight and rigidly enforced. The frame should provide several inches of clearance above the floor to prevent the filters/adsorbers from contacting any liquids which may collect there. (See Chapter 4 of reference 7.)

Filter units and adsorber cells must be clamped to the mounting frame with enough pressure to enable the gasket to maintain a reliable seal when subjected to vibration, thermal expansion, frame flexure, shock, overpressure, and widely varying conditions of temperature and humidity that can be expected in service. Clamping devices must function easily and reliably after long exposure to hostile environments and, in addition, must be capable of easy operation by personnel dressed in bulky protective clothing while working in close quarters. Experience has shown that a simple nut-and-bolt system gives satisfactory service under these conditions.

The magnitude and uniformity of pressure are important factors in clamping filters and adsorbers. At least four pressure points are required. While individual clamping of each element is preferred, common bolting in which the holding-clamp space nut bears on two or more adjacent filters or adsorber cells is acceptable in the demil field. The specific clamping mechanism is generally an integral part of the mounting frame design and can vary from manufacturer to manufacturer.

For CAMDS the filter unit manufacturer designed the mounting frames and clamping mechanism. The mounting-frame configuration is the third or drawer type listed above. Two sections of mounting frames, one in a type I unit and the other in a type II unit, are shown in figures 4-16 and 4-17, respectively. A more detailed discussion of mounting frame design and sealing is given in Chapter 4 of reference 7.

The manufacturer used different types of clamping mechanisms for the type I and type II/type III housings. Toggle clamps* were used in the type I units. Their quick-release design permits them to be released or tightened by a simple single movement, which is ideal when working through a changeout bag. The type II and type III

*Product of De Sta Co. Division, Dover Corp., Detroit, Michigan

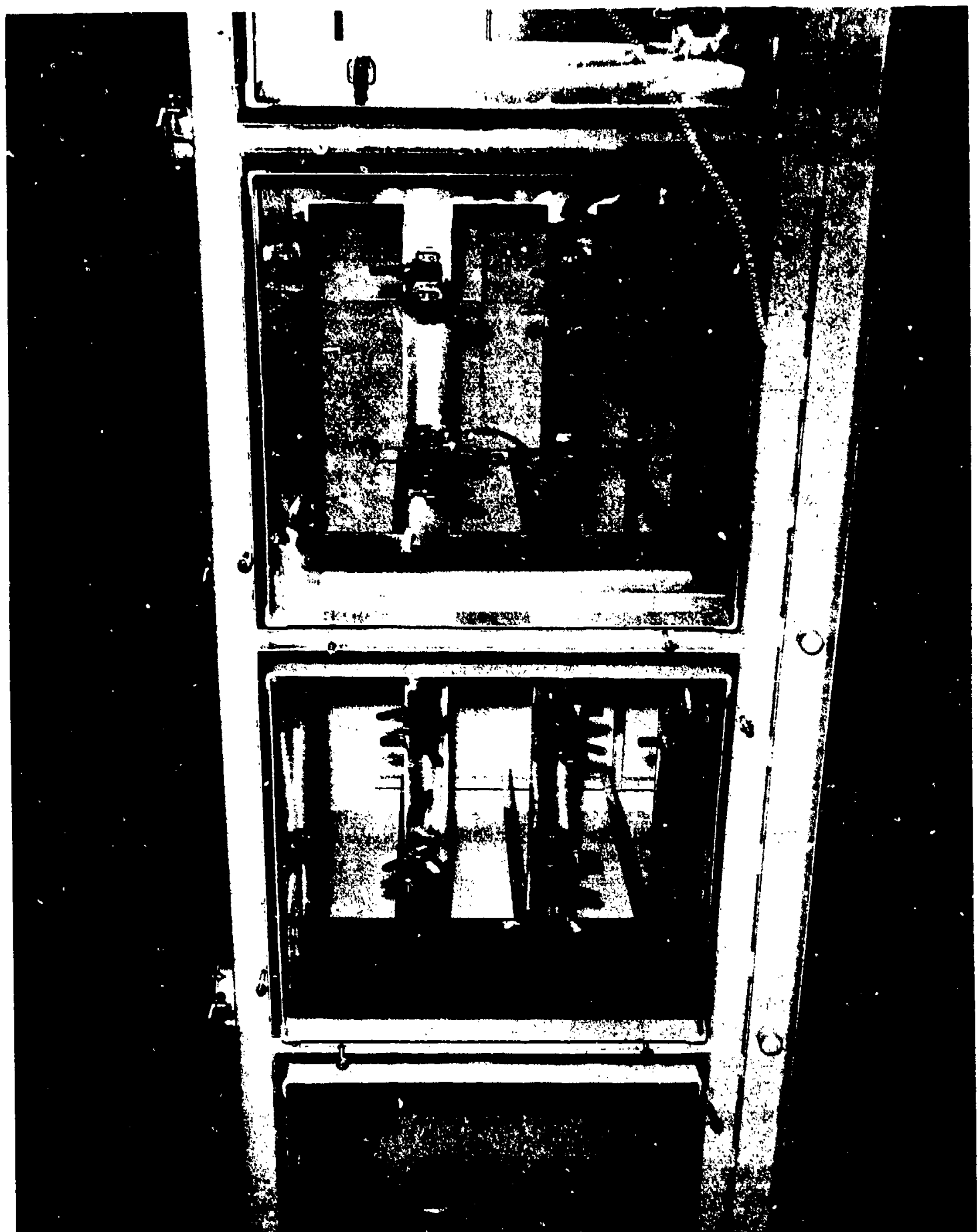


Figure 4-16. Mounting Frame In Type I Filter System (1,000 Cfm)

Figure 4-17. Mounting Frames In Type II Filter System (6,000 Cfm). Adsorber (Bank No. 4) Mounting Frames Are In Foreground And HEPA Filter Mounting Frames (Bank No. 5) Are In Rear

units use a captive-nut clamping arrangement. Here the handle on the nut is sufficiently large to enable personnel wearing protective gloves to turn it tightly. See figures 4-18 through 4-22 for illustrations of both types of clamping techniques. Regardless of which clamping method is used, the gasket must be sufficiently compressed (approximately 50% for neoprene*) to assure an airtight seal.

The location of the studs on the mounting frames are determined by the basic sizes of the face plates and outer flanged surfaces of the adsorber units, which are standardized by AACC CS-8[10]. Therefore, an adsorber cell from one manufacturer should fit another manufacturer's mounting frames. Potential problems of incompatibility were avoided at CAMDS by having the same manufacturer select the cells and mounting frames. HEPA filters, in order to mate with standardized mounting frames, must be 24 in. x 24 in., as governed by AACC CS-1.[18]

The mounting frames for all components in type I units at CAMDS were made from type 316L stainless steel. In the type II units, all adsorber mounting frames were also constructed from type 316L stainless steel, while the particulate-filter mounting frames were made from carbon steel coated with epoxy paint.

The gasketing surfaces required to insure a leaktight seal are an integral part of the cells and are, therefore, discussed with those items in section 4.1.2.4.

4.1.2.3. Access Doors

There are two basic types of access doors, one for type I housings (reach-in) and one for type II/type III housings (walk-in). Both types must be provided with gasket seals to assure leak-tightness and to maintain a hermetic seal equal to at least the fan cutoff pressure. For access to the housings, doors must be removable or open outward.

Although various types of door designs are possible, two types considered at CAMDS for type I housings are illustrated in figure 4-23. One method seals the door against the flange of the access opening (figure 4.23a), while the other method seals the door against the housing frame (figure 4.23b). The required compression for sealing in both cases is obtained by torquing a nut onto a stud to a specified value (120 in.-lbs. at CAMDS).

*ASTM D1056 Grade SCE-43.[9]

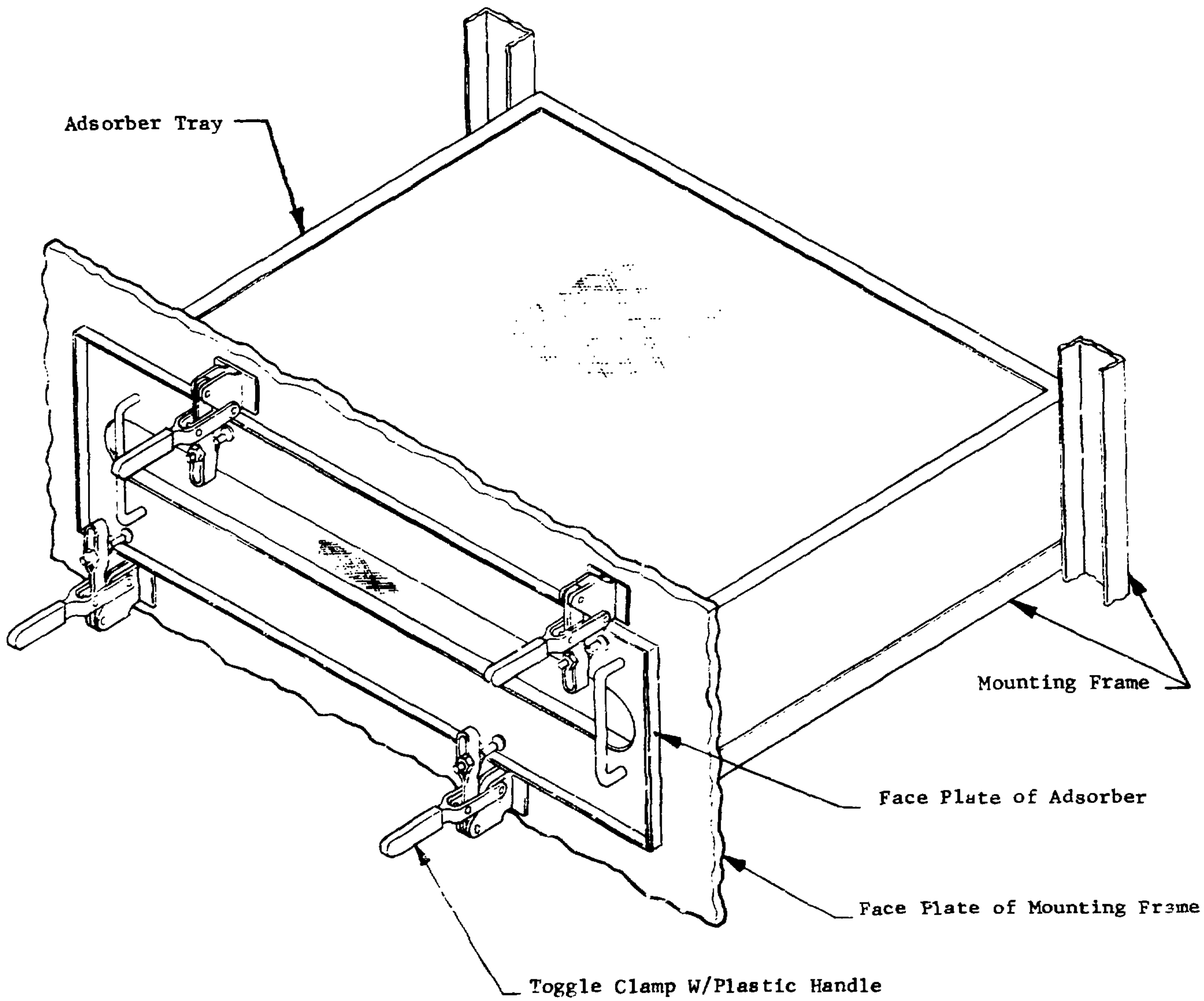


Figure 4-18. Quick-Release Toggle Clamps In Type I Filter System

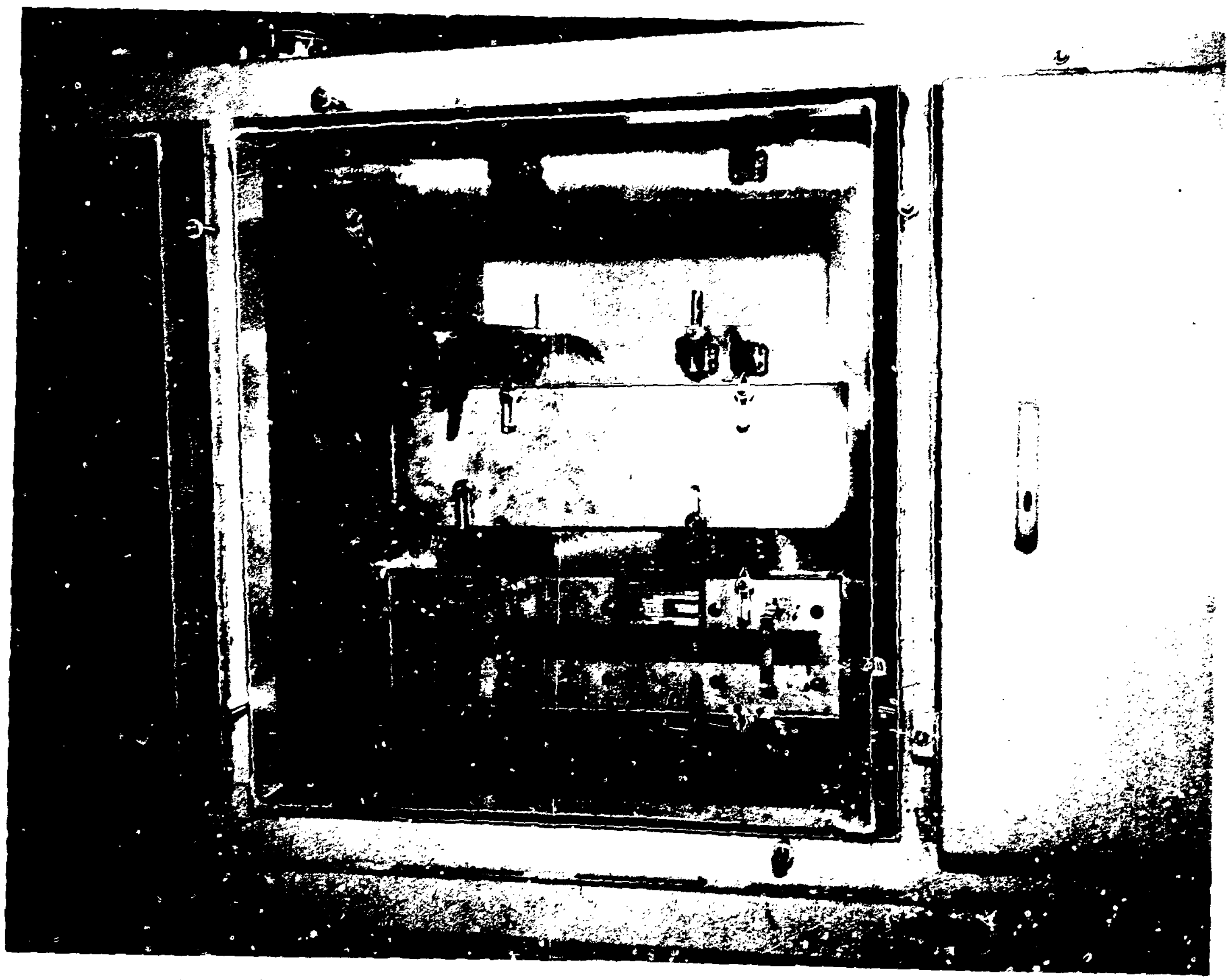


Figure 4-19. Type I Filter System (666 Cfm) Using Quick-Release Toggle Clamps On Adsorber Tray And Blankoff Plate

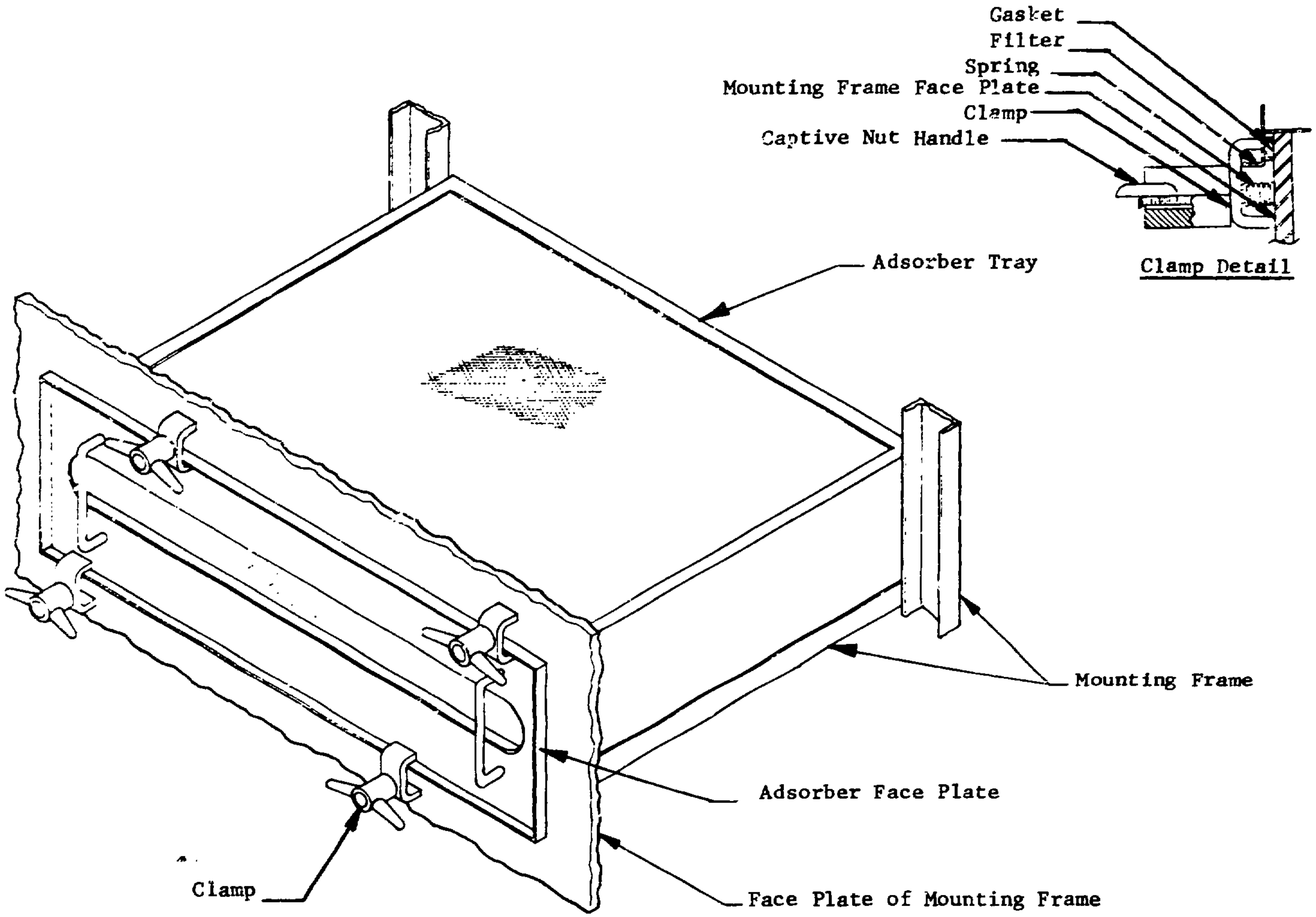


Figure 4-20. Captive-Nut Clamping Arrangement For Type II Filter System

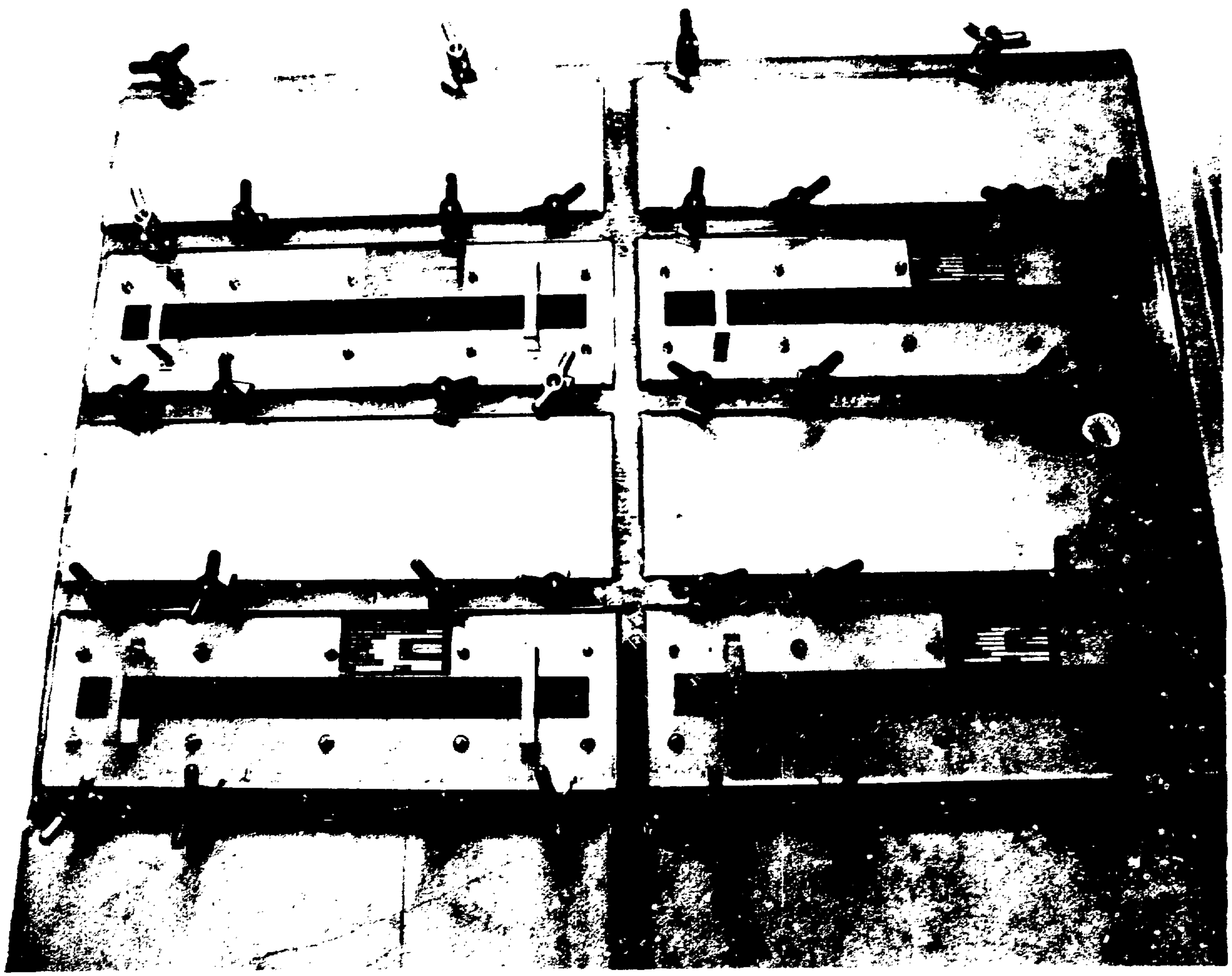


Figure 4-21. Bank Of Adsorber Trays And Blankoff Plates Using Captive-Nut Clamps. This Is 3,000 Cfm Arrangement In 6,000 Cfm Type II Filter System

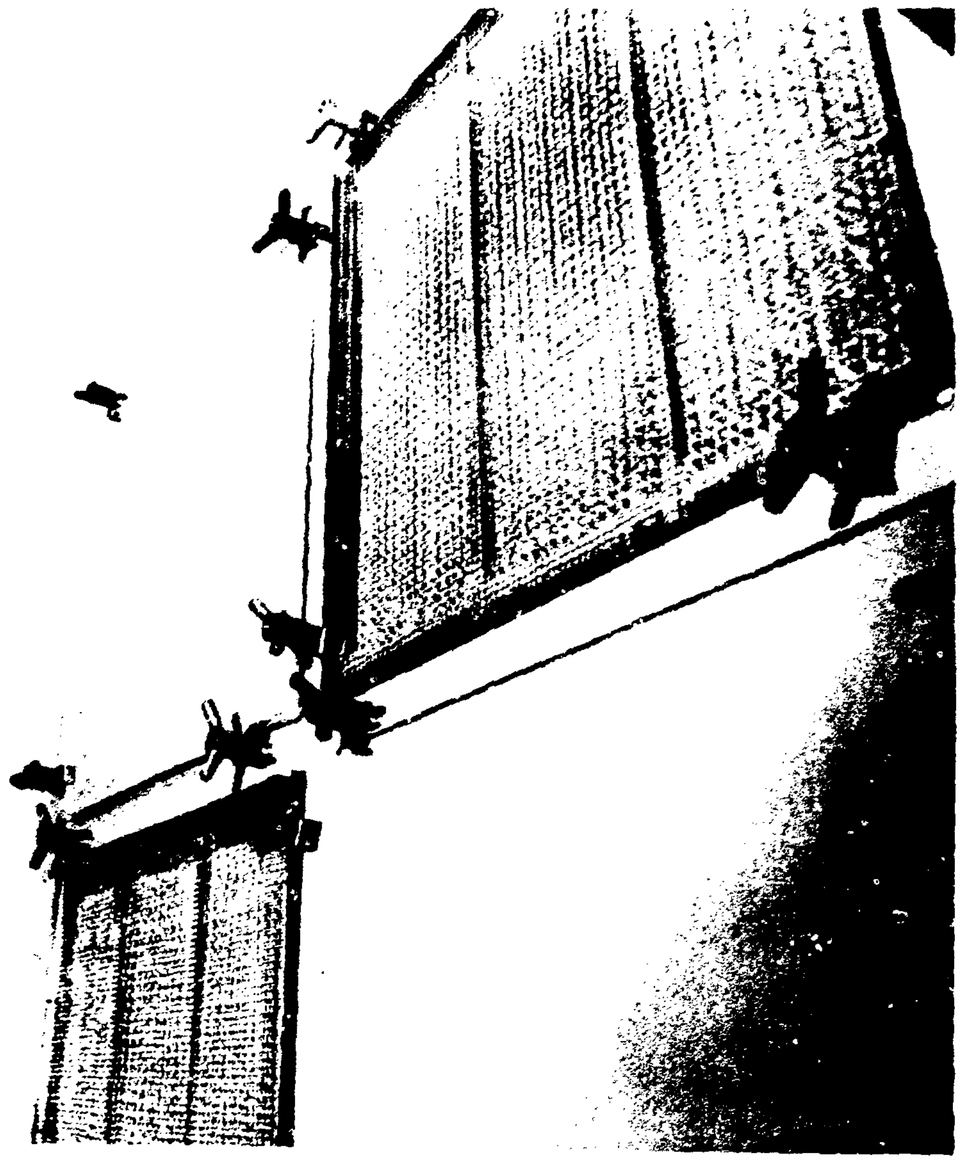
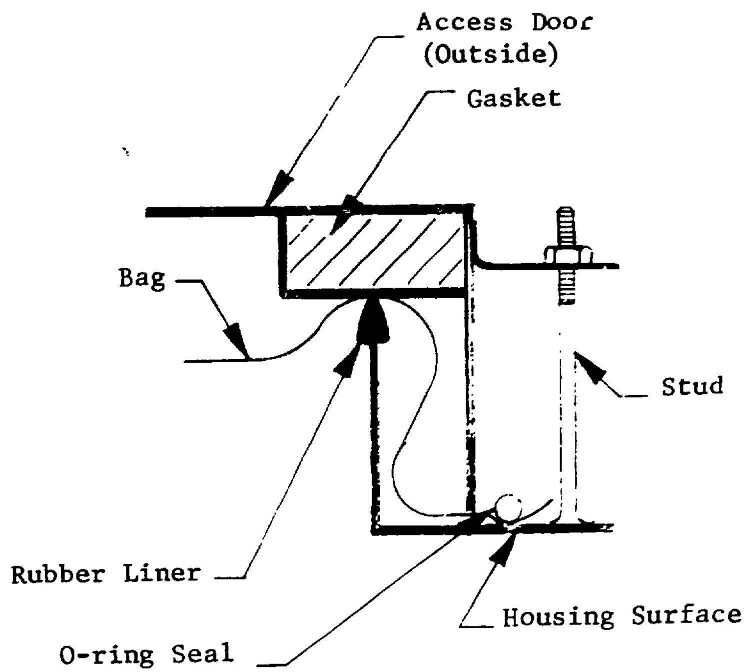
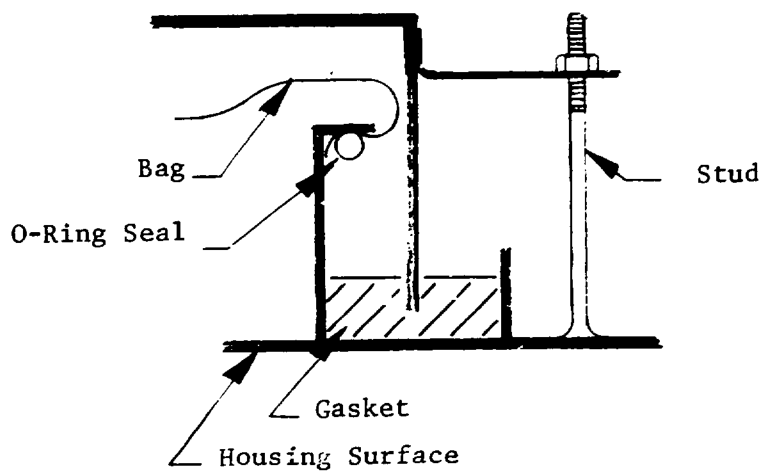


Figure 4-22. Bank Of HEPA Filters And Blankoff Plates Using Captive-Nut Clamps. This Is 3,000 Cfm Or 4,000 Cfm Arrangement In 6,000 Cfm Type II Filter System



a. Method A



b. Method B

Figure 4-23. Access Door Sealing Methods For Type I Filter Housing

Based on CAMDS experience with these door designs, the configuration shown in figure 4-23b (Method B) is preferred. Two major problems developed with Method A, namely:

1. The portion of the bag in contact with the door gasket became rigid and cracked; this was probably due to an interaction between certain chemicals in the PVC bag and the neoprene rubber gasket.

2. The portion of the bag extending outside the door and exposed to the elements began to deteriorate; this was probably caused by ultraviolet rays from the sun.

Both of these problems may possibly be overcome by a change in bag material (see section 6.4.2.1), but at considerably more expense. Method B eliminates the problems entirely.

Walk-in doors, such as those of type II and III housings, are similar to marine bulkhead doors. They are of sturdy construction with rigid close-fitting casings and positive latches. Housing doors should have heavy-duty, double-pin or slip-pin hinges, and a minimum of six latching devices (called "dogs") operable from either inside or outside. (See figures 4-12 and 4-13.) Door rigidity or stiffness is important since flexible doors can be sprung or deformed when opened against negative pressure or allowed to slam shut when under load. (A more detailed discussion of housing doors is presented in section 4.5 of reference 7.)

All walk-in access doors at CAMDS are 30 in. by 60 in. with one door for each compartment requiring entry, as specified by CSL safety officials. This is the minimum opening required for workers in protective clothing. Each door uses six latches, three on each side, for effective sealing.

4.1.2.4. Gasketing

Gasketing is required to ensure leaktight sealing of components and the filter housings. The three major areas in which gaskets are used in such applications are:

1. Between filter/adsorber cells and the mounting frame. The gasket is bonded to the cell rather than to the mounting frame, permitting it to be replaced each time the filter or adsorber is changed. These are made of fairly soft, closed-cell, neoprene sponge, ASTM D1056, Grade SCE-43.[9]

2. Between flanged connections on various sections of ductwork. These are a somewhat harder (less compressible) material,

as indicated in the CAMDS ductwork specification (see Appendix E of reference 11).

3. In the filter-housing access doors, where the properties for this gasketing material are similar to those of the latter application.

A neoprene gasketing material was used in the doors (application 3) of the first 12 CAMDS housings. Although the desired sealing was obtained, it was found that the gaskets took a severe compression-set over a period of time. As a result, the final CAMDS unit and DATS unit (section 8) now employ silicone rubber gaskets. Based on preliminary results, the latter gaskets have performed satisfactorily.

Another factor to be considered in the selection of gasketing material is its compatibility with both the contaminant of interest (chemical agent in this case), and other constituents or potential constituents of the air stream, including SO_2, NO_x, and ozone. Since there is limited information available on this subject, it is suggested that CSL be consulted.

4.1.2.5. Sampling Ports and Inspection Ports

Sampling ports are penetrations through the filter housing for the purpose of (1) connecting sampling lines to agent monitoring equipment, and (2) taking upstream and downstream samples for DOP and freon testing of filters/adsorbers (section 7). For uniformity, each sampling port should consist of a one-in. diameter (minimum) NPT half-coupling welded in place to prevent leakage. All penetrations should be sealed with a pipe plug, using a suitable thread sealant (such as teflon "ribbon dope"), when not in use.

An inspection port is an opening in the housing which allows personnel to visually examine the interior of a specific compartment with the aid of a flashlight or permanently installed overhead lights (certain walk-in units only) without having to open a door or enter the area. The inspection port is normally covered with either a bolted-on metal plate, which is removed when observations are to be made, or a clear plastic cover. Inspection ports can also be used for test purposes by incorporating a one-in. diameter NPT half-coupling and inserting a sampling probe in the cover plate. These ports may also be used for connecting flexible-tubing "jumpers" to enable the testing of series banks of filters and/or adsorbers, if a flange or rim is provided to which the flexible tube may be sealed. (See figure 8.16 of reference 7.)

At CAMDS the type and locations of sampling and inspection ports vary from unit to unit as indicated in table IV-4. Each housing, however, contains at least two sampling ports between the two adsorber banks. The couplings are made of type 304 stainless steel. Two sampling ports are specified per housing to allow simultaneous use of two different types of agent monitors.

Table IV-4. Location of Sampling Ports and Inspection Ports in CAMDS Filter Housings

Filter Unit	Sampling Port	Inspection Port
333 cfm	6 ea., 1 in. NPT 1/2 coupling, on top surface.	3 ea. located on backside of housing (1 for downstream prefilter and upstream HEPA filter no. 1, 1 for downstream adsorber no. 1 and upstream adsorber no. 2, and 1 for downstream HEPA filter no. 2), and 1 on back end for viewing blower.
666 cfm [a]	5 ea., 4 in. dia.,[b] flanged and gasketed, on top surface; 2 ea., 1 in. NPT 1/2 coupling, on top surface.	Same as above.
2,000 cfm	6 ea., 1 in. NPT 1/2 coupling, on top surface.	Same as above.
3,000, 4,000, 6,000 8,000 and 15,000 cfm	3 ea., 1 in. NPT 1/2 coupling, 2 on top surface (between adsorber banks) and 1 on back end for sampling at blower.	6 ea., 1 on each of 5 walk-in doors and 1 on housing to observe upstream side of prefilter bank.

(a) This filter unit is intended for use on DATS only (section 8).

(b) This diameter was increased from regular 1 in. to 4 in. to provide more flexibility during testing.

The sampling lines of both monitoring devices could, if necessary, pass through a single 1-in. diameter opening, but the availability of two such openings provides greater flexibility to sampling personnel.

Views of the sampling/inspection ports of CAMDS housings are shown in figures 4-12, 4-13, and 4-24, and later in figures 8-2 and 8-9.

4.1.2.6. Pressure Taps

Provision must be included in the filter housings for monitoring the pressure drop across, as a minimum, each filter bank (ΔP measurement across adsorber banks is unnecessary). The readouts from these pressure gages provide information on the buildup of solid matter on, or leakage through, the filters. One penetration is required upstream and one downstream of each bank. The pressure taps are pipe nipples or half couplings welded to the top or side of the housing. The taps should be as small as possible and flush with the inside wall of the housing to minimize airflow turbulence. Tubing connects the pressure taps to the differential pressure gages.

In CAMDS, the taps are located on the top of type I housings and on the side, above the access doors, of type II housings.* (See figures 4-12, 4-13, 4-24, and 8-2.) Pressure taps are identical on all the CAMDS units, although a shutoff valve was added to the DATS unit to maintain its integrity during the frequent relocations which it is expected to make.

4.1.2.7. Drains

Floor drains should be provided in housings in which decontamination and/or deluge-type sprinkler protection provision is made. There should be a separate drain for each chamber (that is, the space between each pair of filter banks) since a common drain could allow contaminated air to bypass the filters or adsorbers. Floors must be sloped towards the drain holes to permit easy runoff of liquid, and the housing must be level to ensure proper drainage. The drains should flow toward the access side of the housings and be either capped when not in use or piped to a liquid waste facility.

*Although there are no type III housings now installed at CAMDS, their pressure taps would be located the same as for the type II housings.

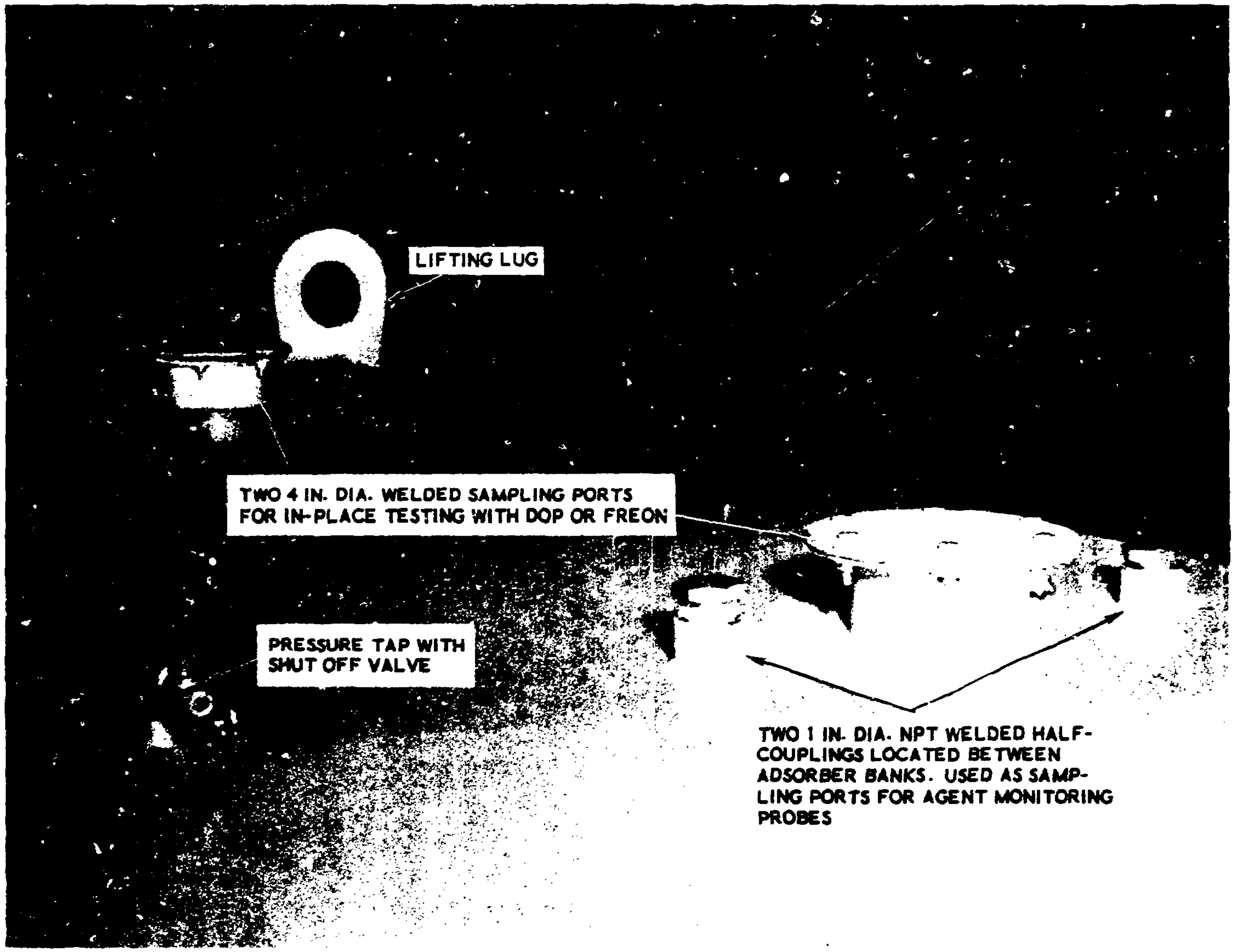


Figure 4-24. Sampling Ports And Pressure Tap On Type I Filter Housing

Each CAMDS filter housing is equipped with six drains, each of which is a 1-inch diameter pipe nipple for connection with outlets installed in the housing skin. A pipe cap seals each drain outlet when not in use and is removed only when a definite requirement exists for decontaminating or flooding the housing. When used, pipe or tubing is connected from the drain to a storage vessel or sump where the effluent liquid - probably contaminated - is collected for disposal. A pump (or pumps) can be incorporated into the system if necessary. (See figures 4-7, 4-10, 4-12, 4-13, and 8-2.)

4.1.2.8. Paint

Carbon-steel housings must be painted to protect against corrosion and to facilitate cleaning and decontamination. Mounting frames may be either carbon steel, which requires painting, or stainless steel (e.g., type 316L). The paint for mounting frames should be hard enough to resist scratching during filter changeout. For demil applications an epoxy-base paint is recommended because its smooth, hard surface is less susceptible to agent penetration than other types of paint. There are several suitable epoxy paints commercially available; the brand found to be least affected by chemical and decontaminating agents is Rowe Epoloid B, a product of Rowe Products, Inc., Niagara Falls, New York.

All CAMDS filter housings and carbon-steel frames were painted with the latter paint in strict accordance with the manufacturer's recommendations (i.e., one coat of primer 7-W-20 plus two coats of base 5-G-5). These units have now been in the field for one to two years and show no signs of deterioration and less scratching than anticipated. Proper preparation of the metal surface and strict adherence to the paint manufacturer's recommended procedures are critical to achieving a satisfactory paint job.

4.1.2.9. Lights

Permanently installed electric lights are recommended in all type II and type III filter housings to provide illumination for visual inspection, in-place testing, and changeout operations. These lights should be installed in series with an independent control switch located on the outside of the housing. They must be installed in vapor-tight glass globes capable of withstanding the pressures encountered and be replaceable from outside the housing through leaktight openings in the roof of the housing. Wiring for the lights should be installed on the outside of the housing in metal conduit to avoid penetrations through its skin. See figure 4-25.

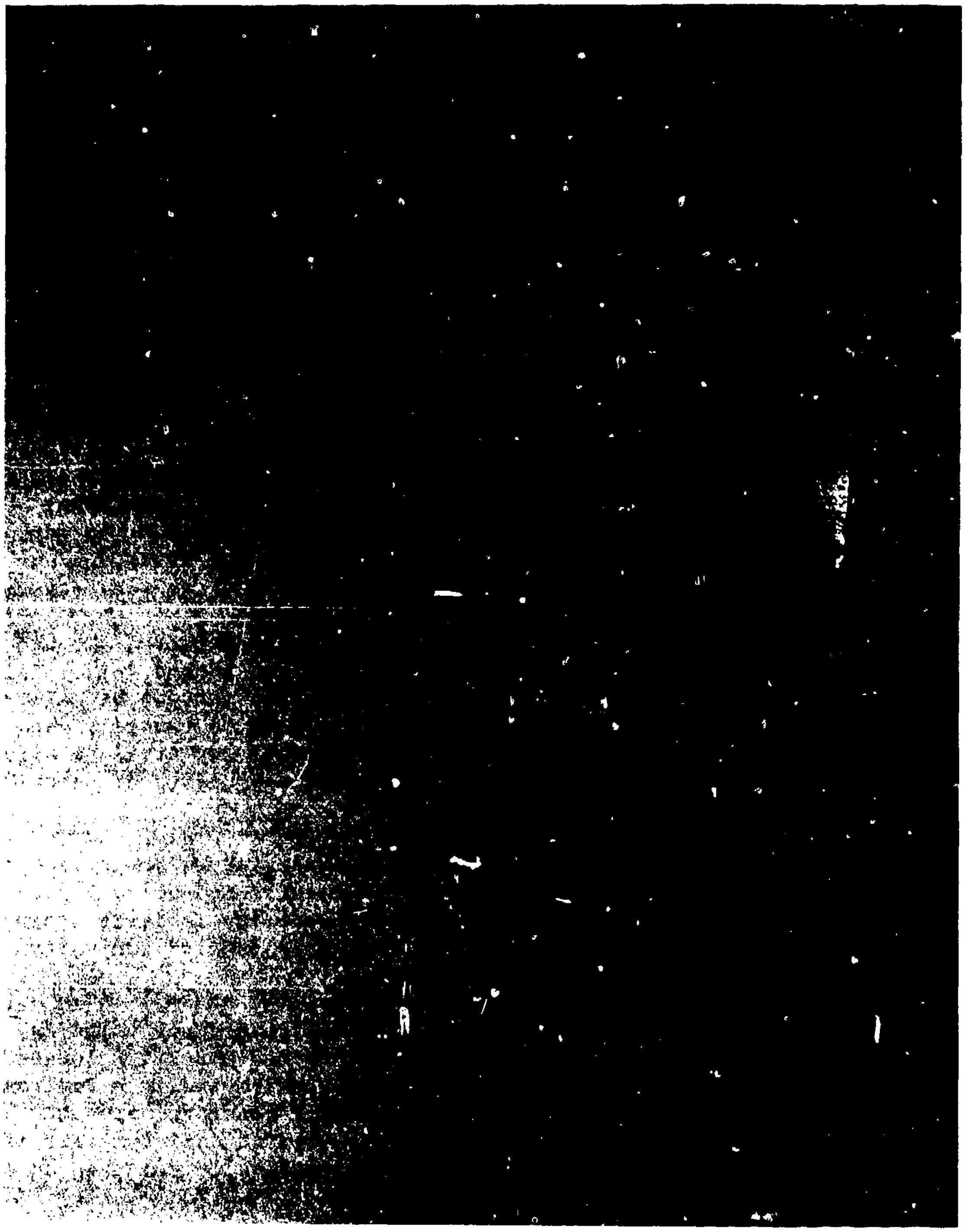


Figure 4-25. Interior View Of Light Fixture And Sampling Port For Type II Filter System

For the CAMDS type II units the light-control switch is located on the back of the housing adjacent to the disconnect switch. There is one light between each pair of banks of the 6,000-cfm housings and two lights between each pair of banks of the 9,000-cfm and 15,000-cfm units. Lights are installed only in spaces where cell changeout occurs. That is, no lights are installed between the first HEPA filter and first adsorber or between the second adsorber and second HEPA filter because no changeout is performed in these areas. No light is installed in the blower compartment because it is considered a clean area without decontamination problems; when needed, a drop-light can be brought in.

4.1.2.10. Electrical

4.1.2.10.1. Power Requirements

Electrical power is required for the fan, interior lighting (type II and type III units only), pumps, heaters, and agent-monitoring equipment for providing signals to the control area to warn of low-flow conditions, etc. In a typical system all equipment except the blower operates from a 110-volt, 60-Hz AC source. The fan usually operates on either 230 (or 208) or 460 volts AC, depending on its size and the power characteristics specified by the fan manufacturer.

All power for filter housing purposes should be connected through a disconnect switch at the housing. See figures 4-7, 4-10 and 4-12. This switch is located at the housing to keep it under the control of maintenance personnel so that power cannot be accidentally turned on remotely when men are working inside. A central control area, however, may still be wired for remote operation of the fans, but without the capability of overriding the local disconnect switch.

At CAMDS the fans operate on 208-volt, 3-phase, 60-Hz power except the ADS units (containing 40 hp motors) which require 460-volt, 3-phase, 60-Hz power. Incoming commercial power to the facility is first stepped down to 480-volts for the ADS fans and then stepped down to 208-volts for the other fans.

In case of commercial power failure, 480-volt emergency power is automatically supplied to the ADS by a diesel-powered generator located in a utility building. Another emergency generator housed in a railroad car supplies 208-volt emergency power. The latter generator operates automatically upon loss of commercial power; should it fail to start after three tries, a backup (redundant) generator automatically switches on to supply the required 208-volt power.

4.1.2.10.2. Type of Power

Before specifying blower requirements, the designer should determine what type of power is available at the demil site. If commercial power is available it usually is stepped down by a transformer to 480 volts, three-phase, 60 Hz and then to 240-volts, three-phase, 60-Hz, or directly to 240-volts. Unless otherwise specified, the motors for the blower units should be selected to operate from the available power sources.

Many military portable generators (for use where commercial power is not available) and certain military facilities, however, supply 208-volt, three-phase, 60-Hz power. If specifically requested from the manufacturer, motors designed to operate from a 208-volt, three-phase, 60 Hz power source can be obtained. It is important that a motor not be run from a different power than that for which it is designed. Although the motor will operate if connected to the wrong power source, its chances of malfunctioning or burning out are significantly increased. Since the blower assembly is critical to the overall ventilation system, it is strongly recommended that its motor be used only at the rated voltage.

4.1.2.11. Blower Assembly

4.1.2.11.1. Fans

The fan in the blower unit must be capable of pulling the required airflow through the ventilated area. Since the total static pressure of the system is not constant but undergoes a continuous slow increase due to dust buildup on the particulate filters, the system must be capable of compensating for the increased static pressure and maintain constant airflow. Two types of flow control systems - (1) centrifugal fan with flow-control damper in the duct, and (2) centrifugal fan with variable axial vanes - have been successfully used to meet these requirements and are recommended for application in chemical demil operations.

The centrifugal fan with external damper must be sized to the maximum static pressure expected and always operated at this maximum condition. When the particulate filters are clean and the total static pressure in the ventilation system is minimum, the control damper is closed sufficiently to increase the static pressure to its maximum level. As the filters gradually clog and build up static pressure, the outlet damper is opened an equivalent amount to maintain constant flow.

In a constant-volume airflow system, however, the fan with external damper is less efficient than the axial-vane fan. The latter must also be sized for the maximum condition anticipated. At startup, with clean filters in the system, total static pressure in the ventilation system is minimum, and the blades close sufficiently to compensate for the

lower level of static pressure through the system. As the static pressure builds up, the blades open up a corresponding amount to keep the total static pressure at a constant value.

With both types of control, the fans accomplish the same function, but the centrifugal fan with axial vanes does less work and thus requires less power. In order to conserve power, the CAMDS specification originally specified axial-vane fans for <u>all</u> blowers; however, the fan manufacturer warned that these units do not operate efficiently at low flow rates and high pressures (5 to 6 in. wg). Therefore, in view of this judgment, centrifugal fans with axial vanes were selected for the larger systems only (8,000 and 15,000 cfm). Fans with control dampers in the stack were specified for all units of 6,000 cfm or less.

To determine the maximum static pressure in the ventilation system, the CAMDS specification (Appendix B) requires that, with a maximum negative pressure of 1 in. wg at the filter inlet, each air filter system shall (1) maintain the specified volume airflow, plus 0 minus 20%, as the filter system's resistance is increased by 100% over its initial value, and (2) maintain the specified volume airflow, plus 0 minus 30%, when the filter system's resistance is increased by 125% over its initial value.

For a more general discussion of fans and flow control, consult Chapter 5 of reference 7 and also reference 12.

4.1.2.11.2. Motors

Based on CAMDS experience, fan motors should be totally enclosed, fan cooled, with double-sealed prelubricated ball bearings designed for continuous operation. Advise the fan manufacturer of the airflow requirements, characteristics of available power (i.e., voltage, frequency, and phase), and basic type of motor desired and let him determine the actual horsepower rating of the motor required for driving the fan. Motor sizes in use at CAMDS range from 2 to 40 hp. (See table IV-1.)

To expedite the lubrication of motors of smaller blower units (2,000 cfm and less), remote greaseports may be considered. These are, in essence, tubes connecting difficult-to-reach lubrication fittings to accessible locations. The lubricant enters the tube and flows through it to the proper lubrication point.

4.1.2.11.3. Drive

There are two basic methods of connecting the blower fan to the motor:

1. Direct drive, in which motor shaft and fan shaft are directly coupled.

2. Belt drive, in which motor shaft is connected to fan shaft by means of a belt-driven pulley arrangement.

For CAMDS, the means of connection was left to the blower manufacturer, who selected belt drive because of its greater versatility. It was stipulated, however, that at least two belts be used on each pulley for redundancy, so that if one belt becomes disabled the blower system can continue operating. (See section 3.4.)

4.1.2.11.4. Capacitors

It is advisable to install capacitors in conjunction with the larger motors in order to improve their power factor. At CAMDS each motor, 10 hp or larger, has a capacitor wired across it which provides a power factor of at least 0.9.

4.1.2.11.5. Vibration

Vibration created in the ventilation system - primarily by fans, motors, and mechanical drives - can be reduced through the use of flexible couplings between the fan and ductwork and springs, or isolation-pad mountings, between the fan and its base. Excessive vibration, if not corrected, can cause damage to components as well as severe noise. If the blower is hard-mounted (i.e., to a concrete pad or solid floor), there is less chance of vibration and isolators may not be necessary.

At CAMDS flexible connections are used between the exhaust section of the fan and the straightening section in the stack in all units above 2,000-cfm capacity. In addition, most of the fans are mounted on damping spring isolators; since recent experience has shown that motor vibration is not extensive enough to warrant use of the springs, some of the later units (2,000 cfm and DATS) are mounted on rubber pads (see figure 4-4).

During shipment between the manufacturer and the CAMDS site, several of the earlier motors equipped with damping springs resonated off their mounts and broke the vibration isolators. To avoid this problem, the motor frames were welded to their housings for shipment, and the welds were removed later after the equipment was set up at the site.

4.1.2.12. Instrumentation

4.1.2.12.1. Introduction

Based on CAMDS experience, there are three basic types of instrumentation required to assure reliable and safe operation of a chemical demil air-filter system. These consist of:

1. Differential pressure gage to indicate static pressure difference (ΔP) across the filter and adsorber banks.

2. Combination differential pressure gage and switch to control the motor driving the outlet damper in the stack or the variable axial vanes on the fan, depending on which type of flow-control system is used.

3. Differential pressure switch to measure airflow (in cfm) for signaling when a low-flow condition occurs.

(See also section 5.1.2 in regard to instrumentation.)

4.1.2.12.2. Differential Pressure Gage

The CAMDS differential pressure gages are Dwyer Instrument Co. 2000-series Magnehelic® gages. These items may be procured with various scales, but for CAMDS a 0-3 in. wg range was chosen since the system is designed for ΔP readings to remain within that range under normal conditions. Five of these instruments, one across each filter/adsorber bank, are connected to each filter housing.

Measurement of differential pressure across adsorber banks is optional and may be done, as it is at CAMDS, for information purposes only. It helps to determine the overall ΔP of the system by including the adsorber segments as well as indicating gross leakage or clogging - although extremely remote - in these banks. The cost for the additional gages is not substantial and the data is of some value to maintenance personnel.

The differential pressure gage is installed by connecting one of its two lines to the pressure tap on the upstream side of the bank and the high side of the gage, and the other line to the pressure tap on the downstream side of the bank and the low side of the gage. The two lines enter the gage where they are separated by a diaphram. The greater the ΔP between the two inputs, the more the diaphram deflects and, correspondingly, the higher the reading in inches of water. The readings thus obtained aid in determining when the particulate filter cells should be replaced due to the accumulation of dust. On the other hand, the adsorber cells capture vapor only and should show no significant change in their ΔP readings unless a significant leak

develops. Therefore, the changeout criteria for the adsorber cells does not depend on differential-pressure gage readings (see section 4.1.3.3.5).

4.1.2.12.3. Combination Differential Pressure Gage and Switch

CAMDS uses another Dwyer instrument known as a Photohelic ® gage, the 3,000-series model with low temperature option. It functions as both a flow indicator and motor-control device. The indicator portion of the gage operates in the same manner as the Magnehelic gage.* In its other function as a double-circuit pressure switch, the Photohelic gage offers high and low limit switches which are activated by separate photocells to trigger relays controlling certain equipment.

Readings are obtained by connecting the high and low sides of the gage to the corresponding high and low ports at the flow-measuring station in the exhaust stack. The flow-measuring station of the stack is a flanged casing containing an air straightener and treatment section, total pressure sensors, tube manifold, static-pressure sensors, and a volume meter (in this case, the Photohelic gage). It is designed to accurately measure airflow through the stack and, therefore, through the filter housing. When the gage reading goes below the lower set-point or above the upper set-point, a contact is closed and an electrical signal is sent out. This signal goes to a motorized damper in the exhaust stack or, in case of the axial-vane fan unit, to a small motor connected to the fan blades. If the signal originates from the low contact, the damper opens or the blades rotate to decrease the resistance to the fan and increase the airflow. The damper or blades continue to operate until the airflow reading moves back, above the lower contact point. When this happens the contact opens and the signal to the motor ceases, causing the motor to stop. The reverse procedure applies if a high signal is transmitted. The flow-control system of DATS is similar (see section 8).

4.1.2.12.4. Low-Flow Signal

For CAMDS, a Dwyer 1910-series differential-pressure switch is used to signal the control room in the event of a low or no-flow condition. This signal actuates an alarm (audible, blinking light, etc.) to inform operating personnel that the airflow is either dangerously low or stopped. Although there is no scale on this instrument, its operation is similar to the switch portion of the Photohelic gage. Its low-flow setting is adjusted by a set-screw.**

*The scales of Photohelic gages used at CAMDS in airflow control systems have been modified to read in cfm rather than ΔP (in. wg).

**The Dwyer 1910-series switch, as used at CAMDS, contains only one set of contacts for use at the low-flow condition; it can be procured, however, with two sets of contacts if signaling of a high-flow condition is also required.

Upstream and downstream readings from the measuring station at the exhaust stack are introduced into the high and low sides of the instrument by air lines. These lines actually connect to T-connections on the lines going to the Photohelic gage.

4.1.2.12.5. Location

The overall flow-control arrangement is shown schematically in figure 4-26, while figure 4-27 shows a closeup of the damper motor and linkage section.

Portions of the automatic flow-control systems in the CAMDS filter units have been deactivated by insertion of an ON/OFF switch between the damper-operating motor and the flow-control gage. This was done because no decrease in airflow resulted in any of the filters to date due to increases in total ΔP, and an automatic flow-control system does not appear to be required. If large flow variations should occur in the future, the automatic control system can easily be reconnected.

The instruments can be mounted outdoors directly on the filter housing or remotely indoors, or a combination of both. CAMDS experience recommends that all gages be mounted remotely indoors whenever possible.

Problems at CAMDS with outdoor-mounted gages involved (1) vibration, (2) fading of the numbers on the face plates by sunlight, and (3) moisture condensation inside the instruments. All of these made reading of the dials very difficult, in addition to shortening the life of the gages. For remote mounting of the gages, the manufacturer claims that, although short lengths are preferred, sensing lines may be extended any necessary distance. A maximum length of 150 ft. is recommended, however, and shorter lengths are preferable. Tubing should be at least 3/16 in. ID to allow the instruments to respond quickly to rapid pressure changes.

At CAMDS all gages, except the low-flow signal, are now remotely located indoors with no line exceeding 100 feet in length. The Model 1910 low-flow signaling switches, however, are mounted on the filter housings. Figures 4-9, 4-11, and 4-13 show how instrument panels were initially mounted on the filter housings. A view of the relocated instruments is shown in figure 4-28.

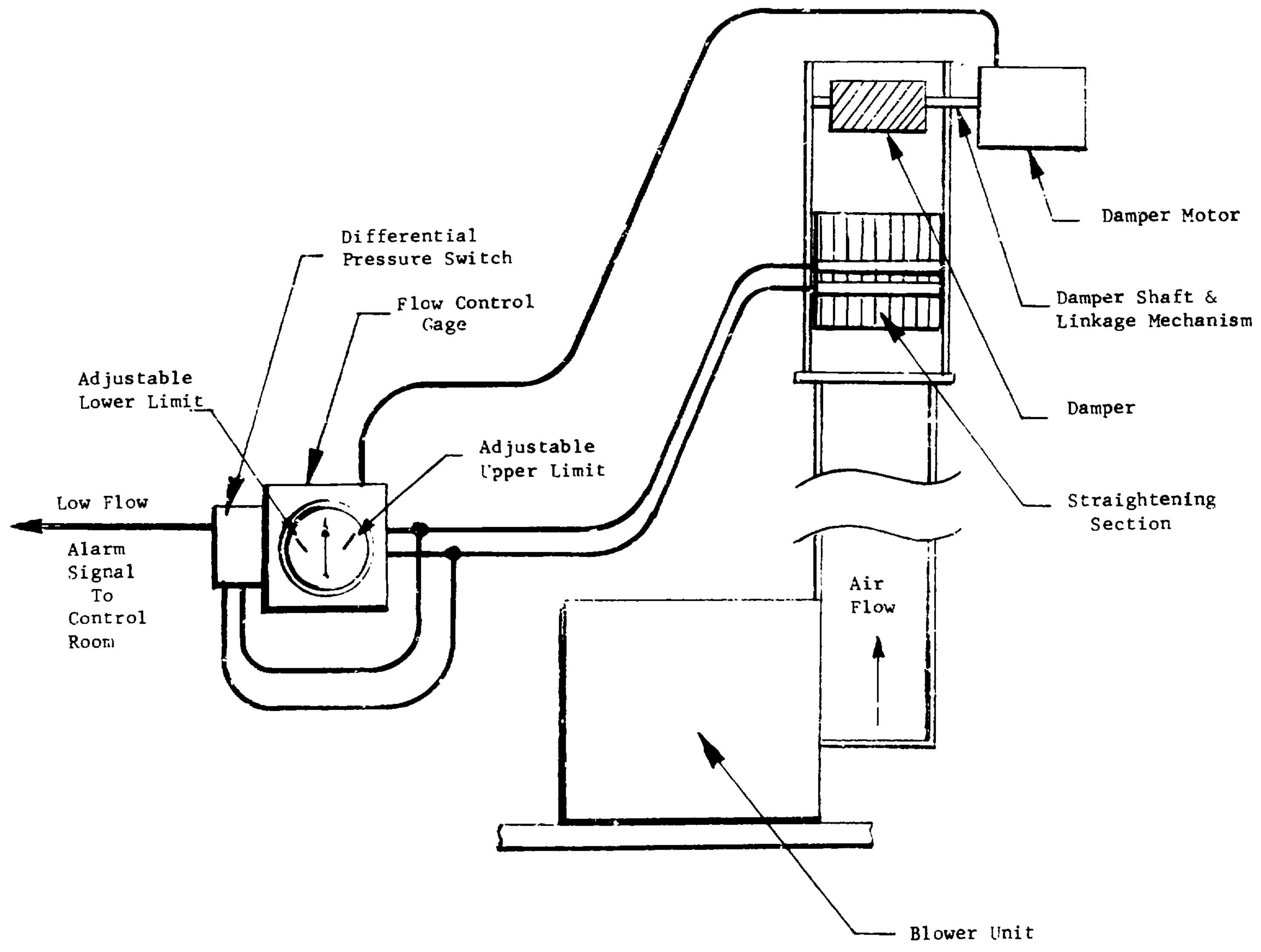


Figure 4-26. Overall Flow-Control Arrangement

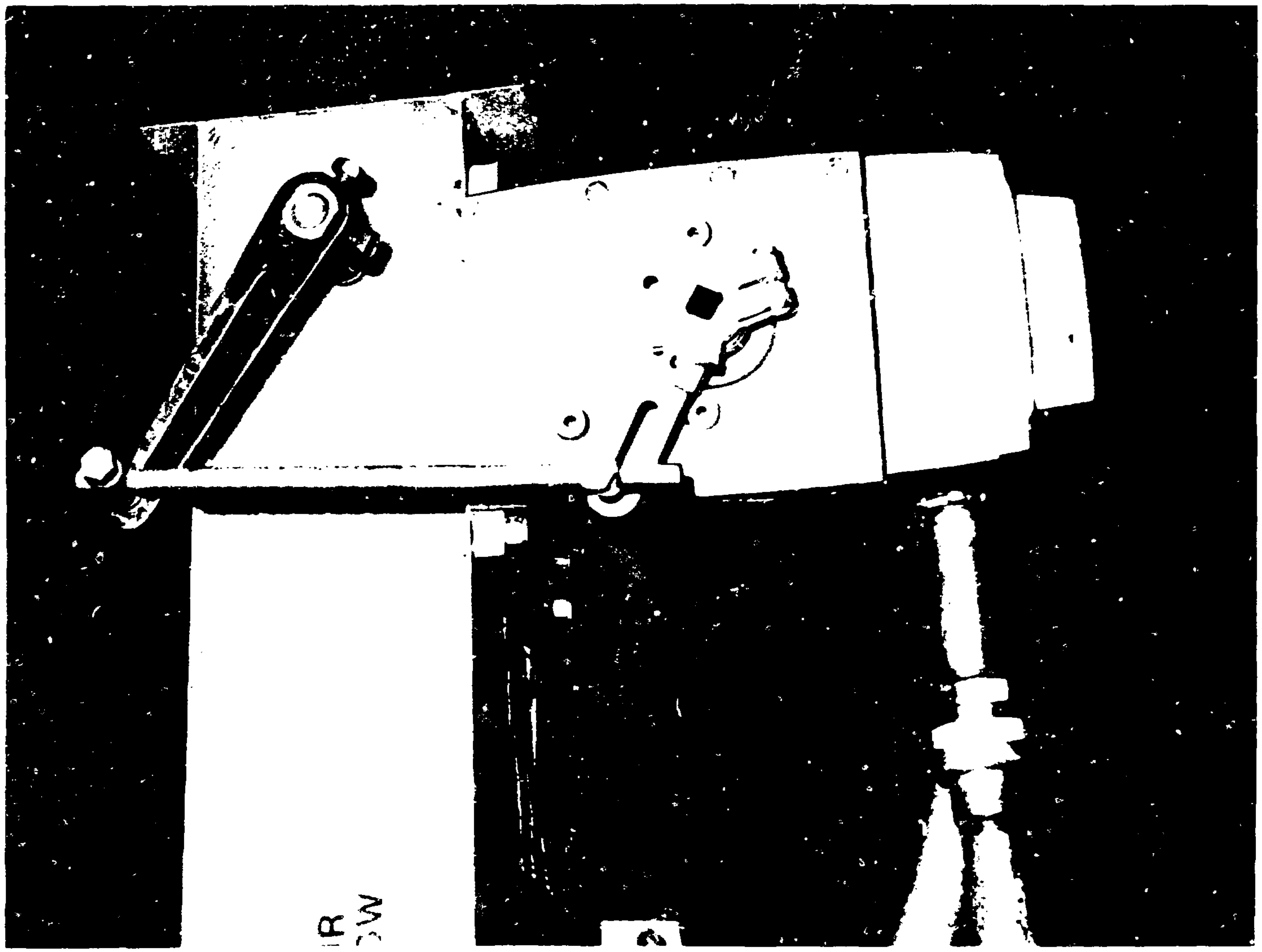


Figure 4-27. Damper Motor (Right) And Linkage Section Of Flow-Control Arrangement

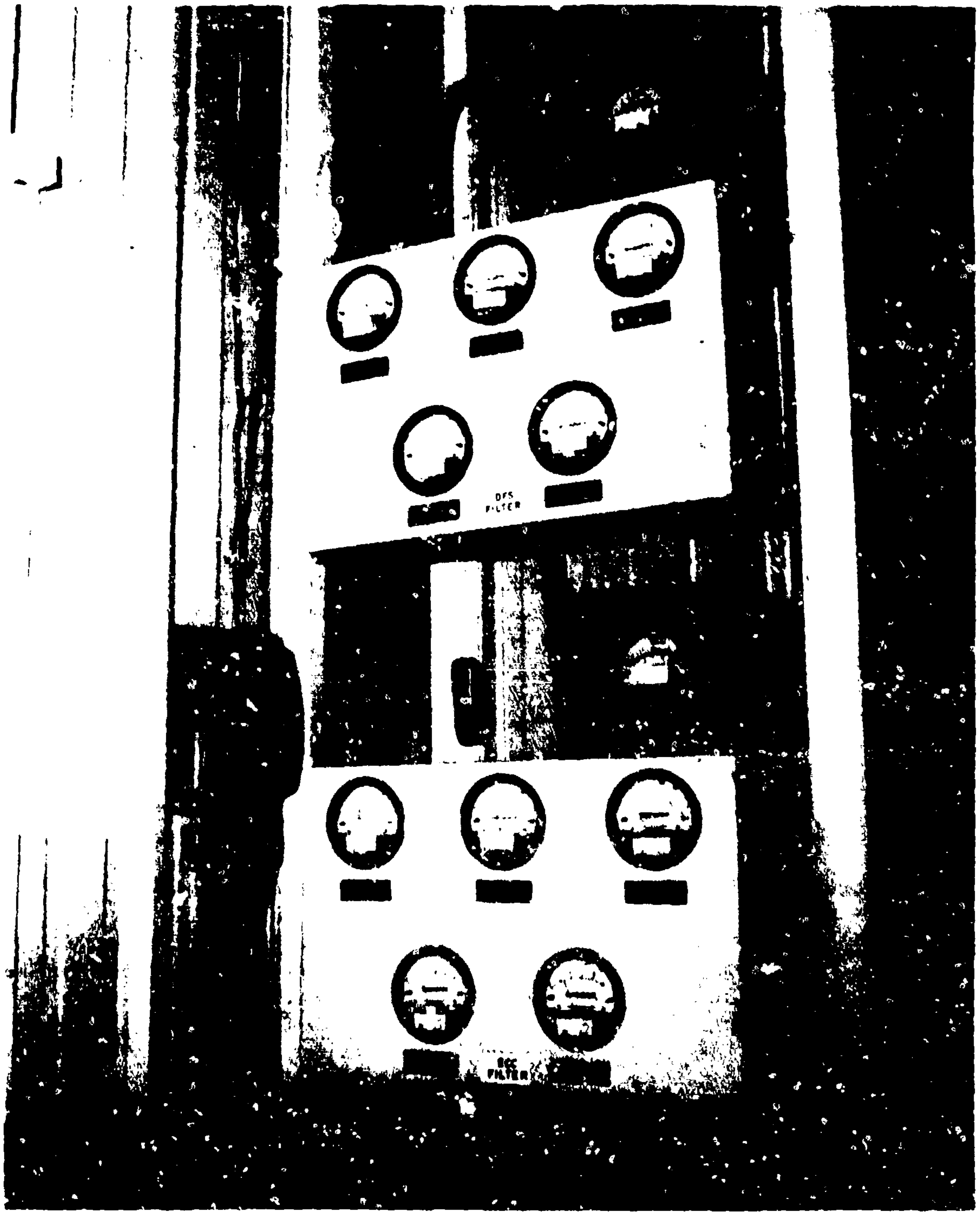


Figure 4-28. Remote Indoor Instrument Station For CAMDS Filter System

4.1.2.13. Exhaust Stacks

There is always the possibility that some amount of contaminated air, even if undetectable, may be discharged through the exhaust of a chemical demil air-cleaning system. Exhaust stacks serve as the means for dispersing exhaust air to the atmosphere. Poor discharge conditions, if there is leakage through the filter system, can result in low-level contamination which may remain in the immediate area or even reenter a ventilated building due to wind effects. Therefore, the type and location of the stacks are key factors in obtaining proper dispersion of exhaust air. Principles of good stack design are illustrated in figure 4-29.

In general, the exhaust stack must be higher than adjacent structures if possible. It should be designed so there is no back pressure to decrease the capacity of the fan. The cross-sectional area of the stack should be not less than the cross-sectional area of the blower's outlet. The vertical-discharge, no-loss configuration shown on the left side of figure 4-30 is recommended.

Sampling ports are provided in the stack to monitor agent concentration in the effluent air and to measure flow rate. One-in. dia. half-couplings or pipe nipples are provided for this purpose. The number of taps required is dependent on the type of sampling intended (agent monitoring or flow-rate determination) and the configuration of the exhaust stack (round or rectangular). See reference 14 and section 5.5 of reference 7 for further details. The responsible USAEHA office should be contacted for specific recommendations and assistance in designing and locating stacks, as well as to insure that all requirements have been satisfied.

After the stack is built it can be tested with commercial smoke-producing devices* to determine airflow patterns across adjacent buildings and to verify that proper discharge is occurring.

The exhaust stacks at CAMDS are of the vertical-discharge, no-loss design illustrated in figures 4-30 and 4-51. All are constructed of 16-gage carbon steel and coated with epoxy paint for corrosion resistance.

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*Smoke candles are recommended for low flow rates and smoke bombs for high flow rates. These devices should not contain titanium tetrachloride, which is highly corrosive.

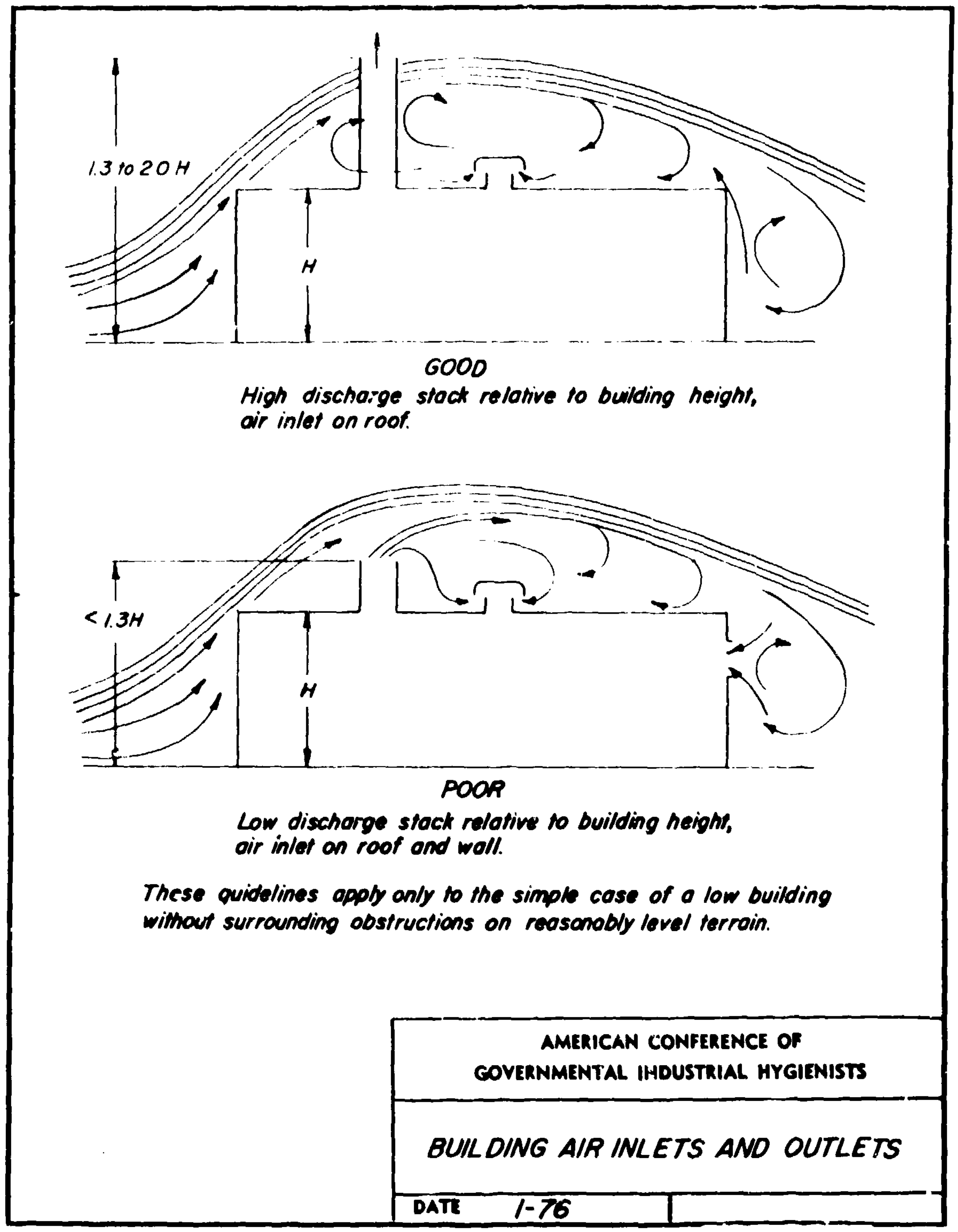


Figure 4-29. Principles Of Stack Height Design

(Courtesy Of American Conference Of Governmental Industrial Hygienists)

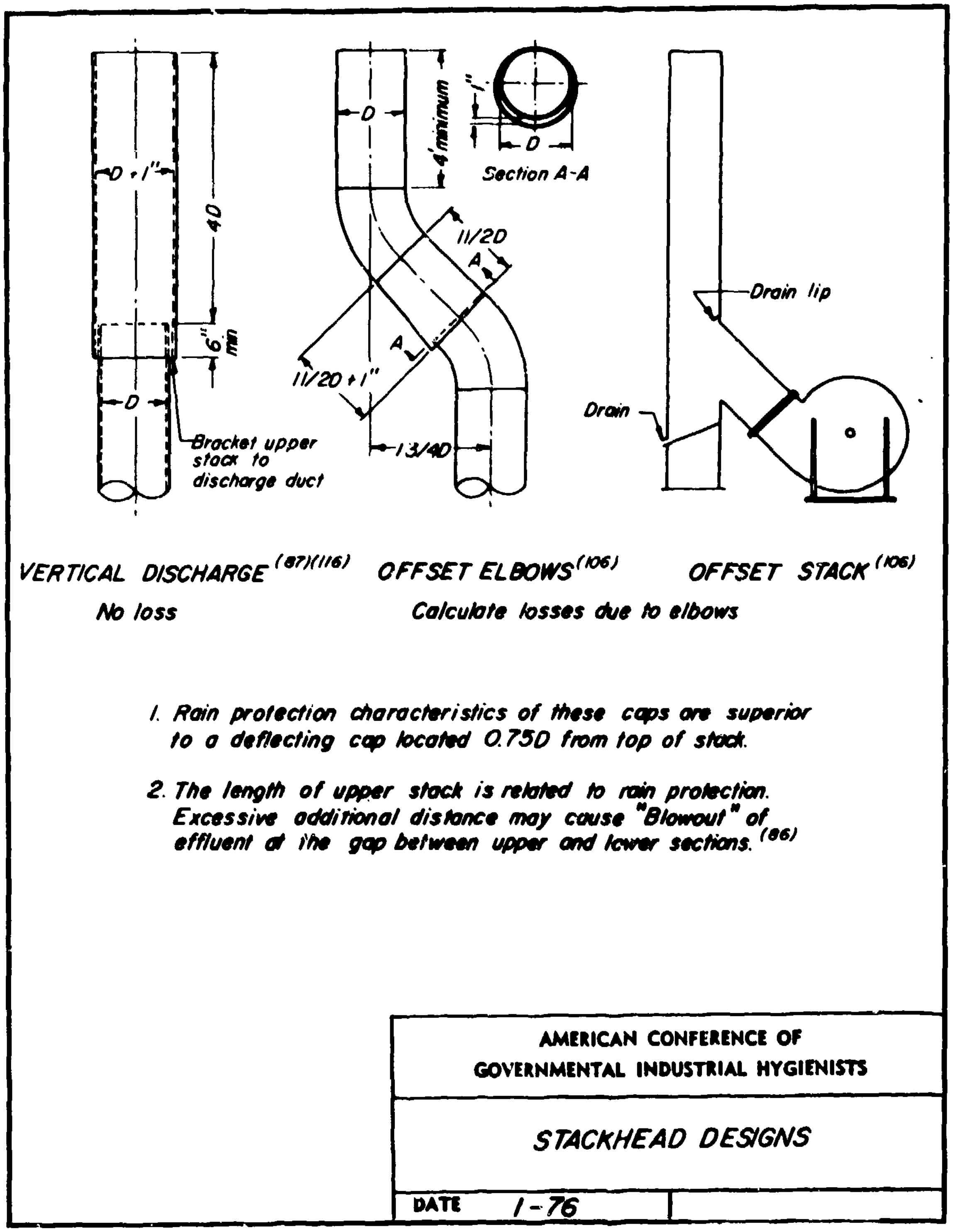


Figure 4-30. Vertical-Discharge, No-Loss Stack Head Design (Courtesy Of American Conference Of Governmental Industrial Hygienists)

4.1.2.14. Skids and Lifting Eyes

Filter housings should be fitted with four external lifting eyes (or lugs) and mounted on skids to facilitate handling and installation by cranes and forklifts (see figures 4-24 and 4-31). The lifting eyes must be located so that the housing will be horizontal when supported from a single crane hook. Mounting on skids also provides space for laying drainpipes under the housings.

At CAMDS the filter housings are skid-mounted and anchored with 1/2 in. dia. bolts to concrete pads. Each unit is electrically grounded to avoid lightning damage.

4.1.3. Filters and Adsorbers

This section describes in detail the heart of the filter system - those components which actually remove contaminants from the airstream. Included in this discussion is information on prefilters, HEPA filters, adsorbers, and adsorbent.

4.1.3.1. Prefilters

4.1.3.1.1. Function

The first bank of filters in a filter system is the pre- or roughing filter. This filter mechanically removes coarse particulate matter from the airstream and protects the first bank of HEPA filters from being plugged or damaged by large particles. A typical increase in HEPA filter life through the use of prefilters is illustrated in figure 4-32. The increase for a specific application is, of course, dependent on the efficiency of the prefilter selected and the nature and concentration of dusts and particulate matter in the ventilation system.

4.1.3.1.2. Cost Considerations[7]

The decision to use prefilters must be determined for each application on the basis of total air-cleaning system costs (including first cost, effect on power costs, and servicing) and the consequences of exposing the HEPA filters to the environment without protection. In general, HEPA filters should be protected from (1) particles larger than 1 or 2 μm in diameter, (2) lint, and (3) dust concentrations greater than 10 grains per 1,000 cubic feet. Resistance (and corresponding power costs), system installation costs, and filter element replacement costs generally increase with increasing prefilter efficiency. Table IV-5 shows relative prices of filters usually used for prefilter purposes relative to the current price of HEPA filters. (Refer to section 4.1.3.1.7 for descriptions of Group I, II and III prefilters.)

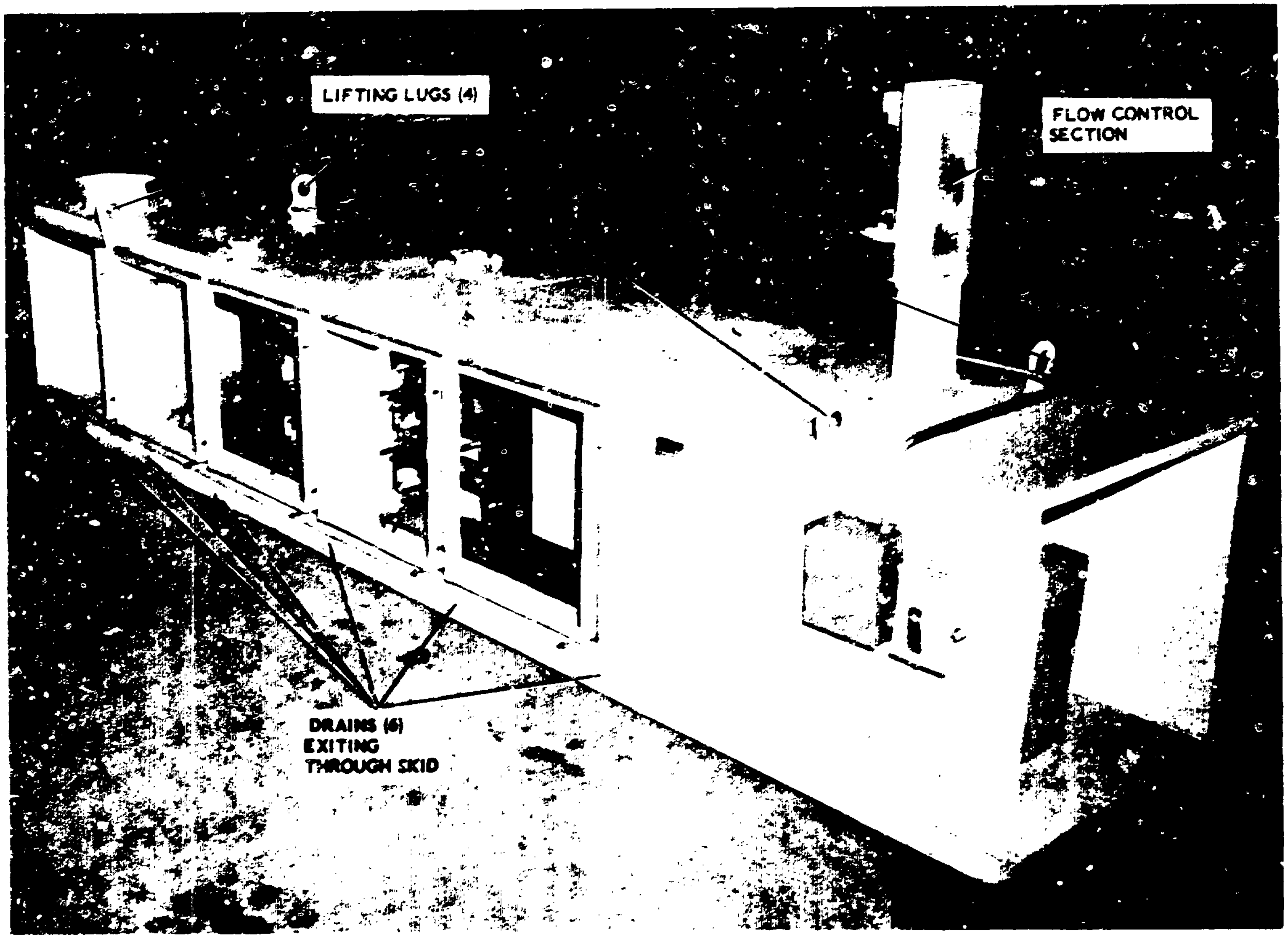


Figure 4-31. Location Of Lifting Lugs On Top Of 1,000 Cfm Type I Filter Housing

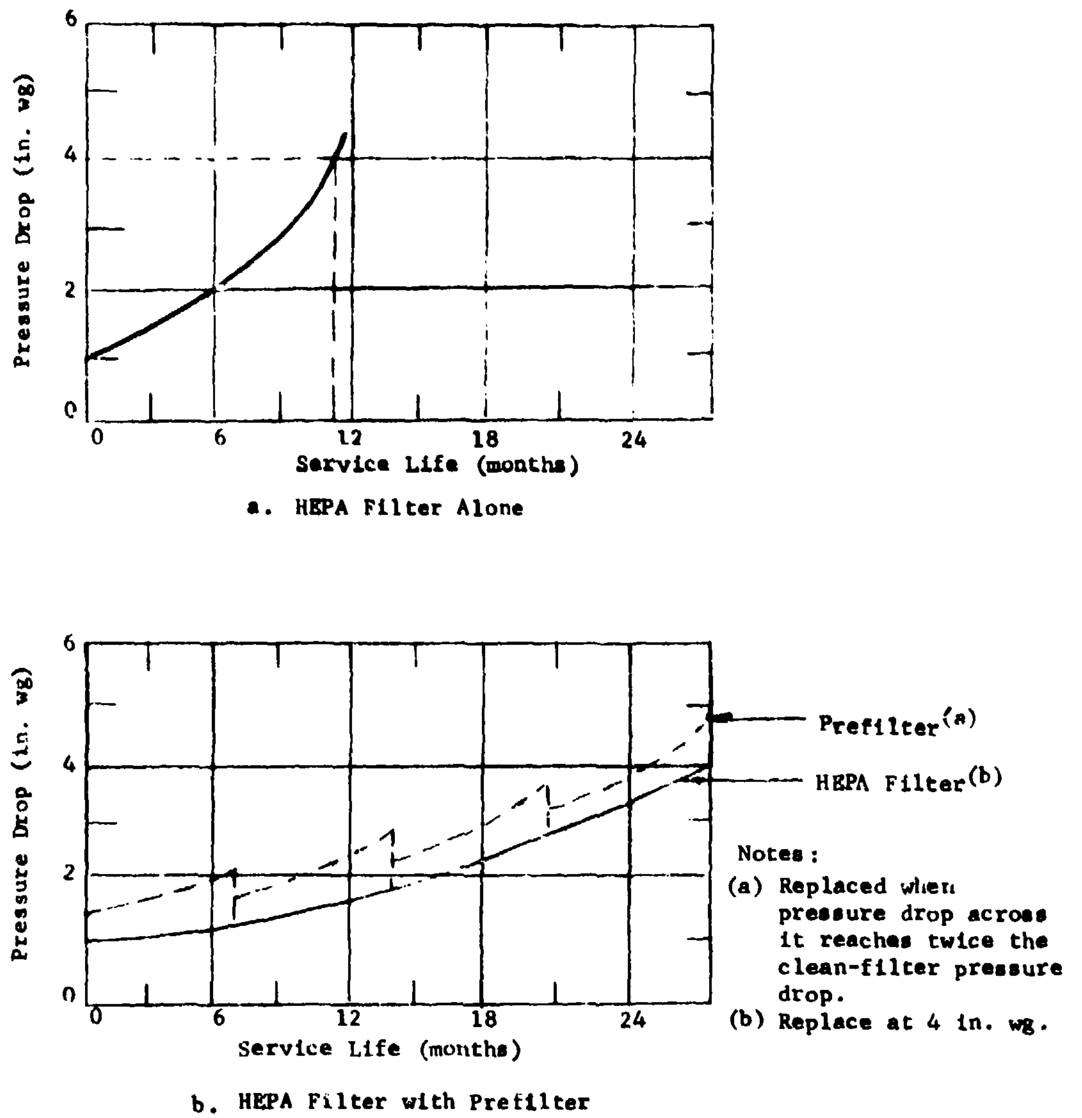


Figure 4-32. Comparison Of HEPA Filter Life With And Without Prefilter (Courtesy Of U. S. Department Of Energy)

Table IV-5. Price Indexes of Common Air Filters Per 1000 Cfm Capacity[7]

Group	Efficiency	Type	Price Index (a)
I	Low	Panel	.01
II	Moderate	Extended Medium	.02-.10
III	High	Extended Medium	.30-.70
-	HEPA	HEPA	.80-1.00

(a) Actual cost may be estimated by multiplying price index by current cost of a HEPA filter; for example, if current cost of 1000-cfm HEPA filter is $130, cost of a Group I prefilter would be .01 x $130, or about $1.30.

4.1.3.1.3. Size

It is recommended, for good air distribution, that the face dimensions of prefilters be approximately the same (i.e., within $\pm$ 1 inch) as the face dimensions of the HEPA filters with which they are used.

4.1.3.1.4. Type

Common air filters used as prefilters are classified as shown in table IV-6. The classification is based on arrestance (weight percent) and dust-spot (stain) efficiency as explained in references 7 and 15. Because the atmospheric-dust spot test is based on the staining effect of the dust that penetrates the filter, as compared to the staining capacity of the entering dust, it is not a true measure of particle-removal efficiency for any given particle size range. Table IV-7 gives a more meaningful comparison.

Table IV-6. Classification of Common Prefilters[7]

Group	Efficiency	Filter Type	Stain-Test Efficiency (%)	Arrestance (%)
I	Low	Panel, viscous impingement	<20[a]	40-80[a]
II	Moderate	Extended medium, dry	20-60[a]	80-96[a]
III	High	Extended medium, dry	60-98[b]	96-99[a]

(a) Using synthetic dust.
(b) Using atmospheric dust.

Table IV-7. Comparison of Prefilters by Percent Removal Efficiency for Various Particle Sizes[7]

Group	Efficiency	Removal Efficiency (%) By Particle Size			
		0.3 μm	1.0 μm	5.0 μm	10.0 μm
I	Low	0-2	10-30	40-70	90-98
II	Moderate	10-40	40-70	85-95	98-99
III	High	45-85	75-99	99-99.9	99.9

4.1.3.1.5. Performance

Prefilter performance is defined in terms of (1) particle-removal efficiency, (2) resistance to airflow (i.e., differential pressure), (3) airflow capacity, and (4) dust-holding capacity. Table IV-8 gives the comparative performance of Groups I, II and III filters averaged over the life of the filter to the manufacturer's recommended maximum pressure drop.

Table IV-8. Airflow Capacity, Resistance, and Dust-Holding Capacity of Prefilters[7]

Group	Efficiency	Airflow Capacity (cfm per square foot of frontal area)	Resistance (in. wg)		Dust-Holding Capacity (g per 1000 cfm of airflow capacity)
			Clean Filter	Used Filter	
I	Low	300-500	0.05-0.1	0.3-0.5	50-1,000
II	Moderate	250-750	0.1-0.5	0.5-1.0	100-500
III	High	250-750	0.20-0.5	0.6-1.4	50-200

The airflow capacity of prefilters should be the same as or greater than that of the HEPA filters with which they will be used.[7,16] The prefilters at CAMDS are designed to withstand an airflow producing a pressure drop across the filter of at least 5 in. wg for at least 15 minutes without visible damage or loss in filtration efficiency. The manufacturer should furnish a test report verifying that the filters meet this requirement.

4.1.3.1.6. Fire Resistance

The prefilter shall be rated as Class 1 (does not contribute fuel when attacked by flame and emits only a negligible amount of smoke) or Class 2 (may contain some combustible material but must not contribute significantly to fire) in accordance with Underwriters Laboratories (UL) Standard 900.[17] The filter shall be listed in the current UL Building Materials List. Class 1 could be very costly and, after only a week or two in the system, could be no better than Class 2 in terms of fire resistance because of the flammability of certain types of collected dust in certain applications.

4.1.3.1.7. Construction

4.1.3.1.7.1 Materials

Materials used in prefilters must be compatible with the agent and environmental conditions prevailing during chemical demil operations. Many filter media cannot withstand acid or caustic fumes. Fiberglass, a common constituent of many prefilters, withstands exposure to most reagents (except hydrofluoric acid and gaseous hydrogen fluoride), but the resin binders used in its manufacture may not. Qualification tests should be made to verify any questionable or doubtful compatibilities (see section 7).

Aluminum parts, such as those serving as separators, may deteriorate after long exposure to sea air or when caustic substances are deposited on them. Plastics have poor heat resistance and generally will not meet UL requirements. Heavy concentrations of water droplets or condensate may plug or deteriorate filters and necessitate frequent filter replacement. In general, prefilters constructed similarly to the HEPA filters used in the same system will have equivalent moisture and corrosion resistance.[7]

4.1.3.1.7.2. Group I Filters (Viscous Impingement, Panel Type)[7]

Group I panel filters (viscous impingement) are shallow, tray-like assemblies of coarse fibers (glass, wool, vegetable, or plastic) or crimped metal mesh enclosed in a steel or cardboard casing. The medium is often coated with a tacky oil or adhesive to improve retention of trapped particles. Disposable, replaceable and cleanable types of panel filters are available. The latter type has metal mesh and is not generally used in contaminated exhausts because of the difficulties and high costs associated with cleaning. Group I prefilters are of little value in chemical demil applications because of their limited effectiveness against small particles (5 μm and less) and because they are rapidly plugged by lint and other fibrous materials.

4.1.3.1.7.3. Group II and Group III Filters (Extended-Medium, Dry-Type)[7]

Group II (moderate efficiency) and Group III (high efficiency) filters are extended-medium, dry-type units. This means the medium is pleated or formed as bags or "socks" to give a large surface area with minimum frontal area, and the medium is not coated with an oil or adhesive. Group II filters are recommended for high lint and fiber-loading applications. The large area of the medium relative to frontal area permits the use of extended-medium filters at duct velocities equal to or higher than those permissible with panel filters.

Group III filters are used when higher efficiency for smaller particles is desired, although their dust-holding capacity may be lower than the Group II filters. Figure 4-33 shows a Group III filter of the type used at CAMDS.

4.1.3.1.8. Selection

For logistical reasons, prefilters of standard design are generally preferred. However, the important advantage of simplified installation must also be considered even if it involves the disadvantage of a special filter design. For this reason, a special-type filter with sealing flange on one face only

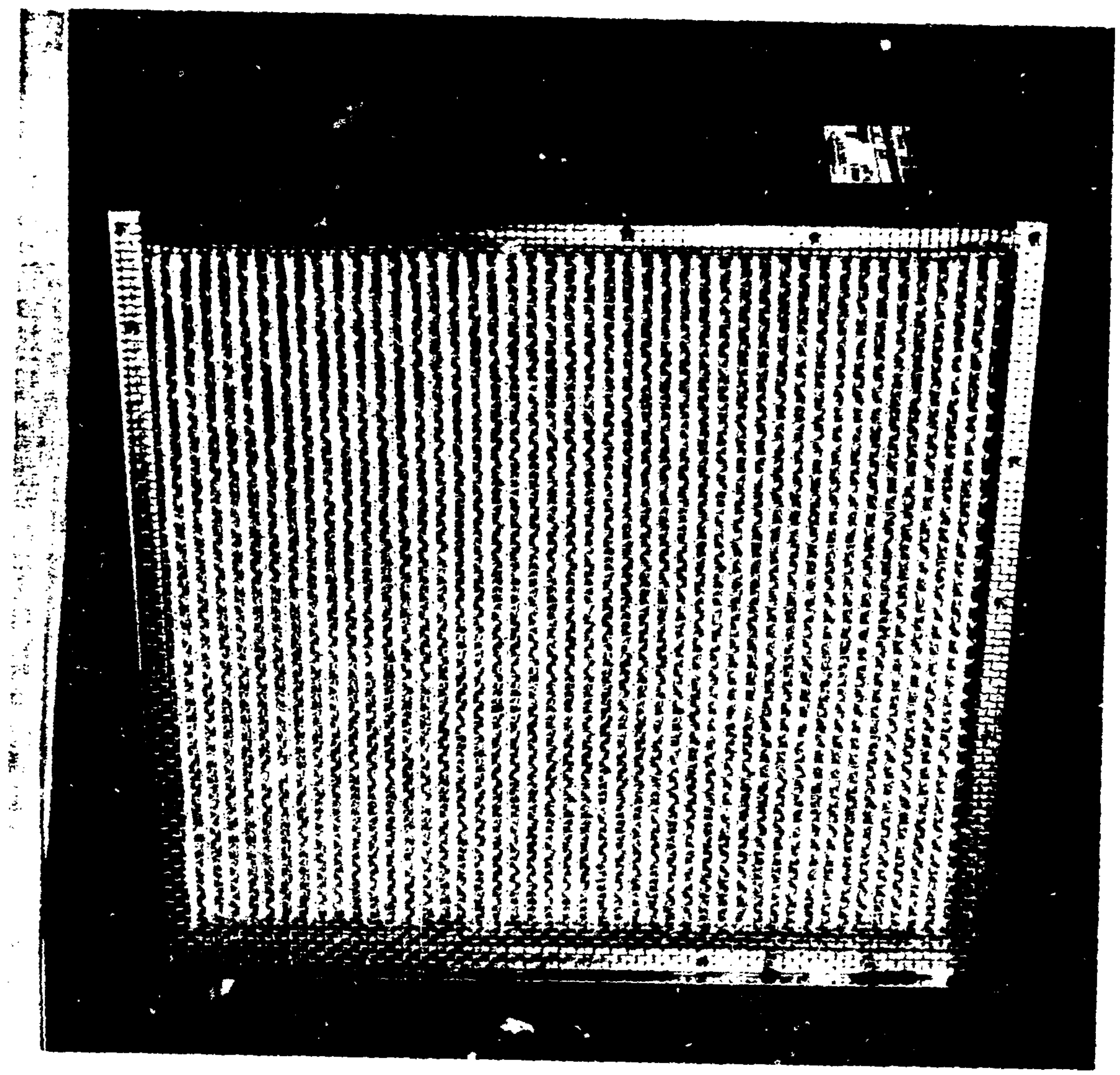


Figure 4-33. Type Of Prefilter (Group III) In Use At CAMDS

was specified for use at CAMDS. This design permits "bayonet" type installation, with sealing at the backside of the flange as shown in figure 4-34. The prefilter meeting this requirement and finally selected for CAMDS was the Model BC81-NL filter manufactured by Flanders Filters, Inc., Washington, North Carolina. This specific model was chosen primarily because it offers the proper flanging configuration for incorporation into the clamping arrangement designed by the filter housing manufacturer.

The filter was obtained by specifying the type, class, group, and efficiency and then letting the filter housing manufacturer (CTI-Nuclear, Inc., Denver, Colorado) procure it to ensure compatibility with the mounting frames. The Model BC81-NL filter is classified as Group III, dry disposable, 80% minimum efficiency[15], UL Class 1.[17] Its maximum dimensions are 24 in. x 24 in. x 11-1/2 in., and it is rated at 1,000 cfm at 0.55 in. pressure drop. Critical pressure-drop values supplied by the manufacturer for the Model BC81-NL prefilter are as follows:

1. Clean-filter differential pressure, 0.55 in. wg.*

2. Recommended differential pressure for changeout, 2.0 in. wg.

3. Maximum differential pressure at which prefilter can be safely used, 5.0 in.

4.1.3.1.9. Installation

Prefilter framing and support equipment in the CAMDS units were furnished by the housing manufacturer as an integral part of the filter housing. Prefilter mounting frames are designed for horizontal airflow. For ease of maintenance, the mounting frames in the type II housings limit prefilter installation to a maximum height of seven feet above the walking surface. Each prefilter is independently clamped in place at a minimum of four pressure points. Common bolting at four pressure points is also acceptable although it was not used at CAMDS.

The filters are mounted on the downstream side of the mounting frames since there is less contamination of the filter casing on this side.

*Actual differential pressure experienced at CAMDS for clean prefilters at rated airflow was 0.2 to 0.4 in. wg.

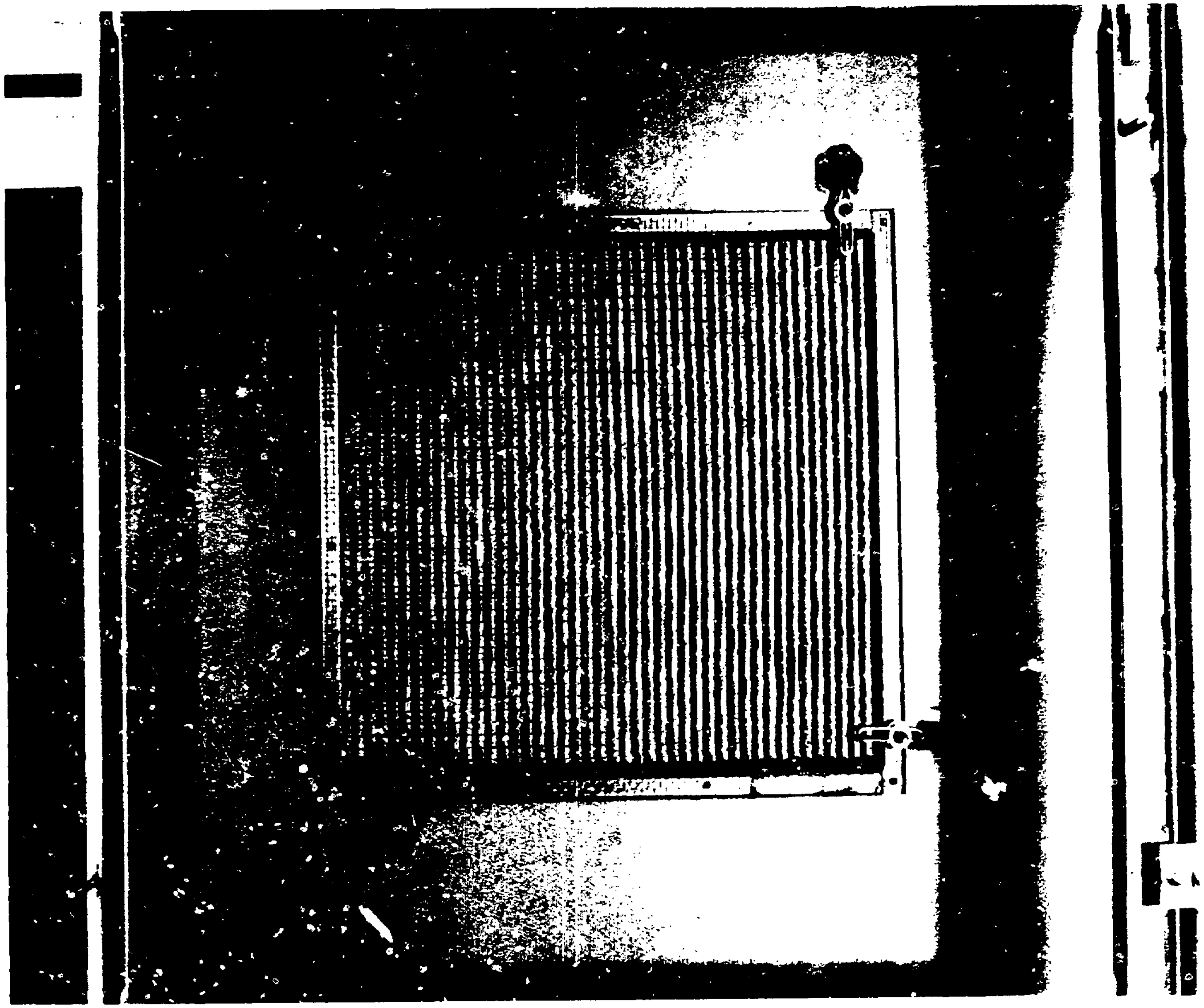


Figure 4-34. Group III Prefilter Installed In Type I Filter Housing. Sealing Surface Is On Rear Of Front Flange.

4.1.3.1.10. Visual Inspection

The following visual inspections should be made of the prefilters before and/or after installation:

1. Prefilters

   a. Damage to or deterioration of shipping carton. This is the first indication of shipping and/or storage damage. If found, the enclosed filters should be closely examined for possible damage or deterioration.

   b. Damage to media, case, or gaskets.

   c. Proper identification.

   d. Adherence to specification requirements.

   e. Installed with pleats vertical.

2. Mounting Frames

   a. Squareness of members, flatness, and condition of component seating surfaces.

   b. Continuous seal-weld between members of frame and between frame and housing. (Sealant must not be used in these areas.)

   c. Structural rigidity.

   d. Damage to frames.

3. Filter Clamping Devices

   a. Proper adjustment (50 to 80% gasket compression all around; tighten if less).

   b. Sufficient number of clamping points (at least four per filter) and adequate size to produce uniformity of gasket compression.

   c. Proper condition of clamping devices (e.g., all nuts in place and tightened).

d. Adequate clearance between filters to grasp them and to tighten clamping devices on all sides.

e. High quality welds and freedom from cracks.

4.1.3.1.11. Changeout Frequency

Pressure drop (or resistance) is the primary factor in prefilter replacement. The prefilter is instrumented with a differential pressure gage to measure the pressure drop across the filter bank. A large increase in differential pressure indicates the filter cell is plugged and requires changeout. A decrease in differential pressure indicates that the prefilter has a hole, tear or leak which also requires filter replacement. It is recommended that the pressure drop be checked and recorded daily to provide a history of differential pressure data as a guide for future operation and servicing.

Changeout should occur when the maximum allowable pressure drop suggested by the manufacturer is reached. A key factor in determining changeout time is the ability of the fan to maintain the required flow at the higher ΔP. If the fan is sufficiently oversized and the filters are capable of withstanding the overpressure, changeout can occur at a higher value rather than the recommended value. The manufacturer's recommended value is not necessarily when filter efficiency decreases, but rather the point above which the filter will clog up (i.e., increase its ΔP) at a much faster rate for a given amount of contamination retained.

As prefilters partially clog due to a buildup of contamination on surfaces, some types (including those used in CAMDS) become more efficient. Since the replacement cost of the prefilter itself is minimal compared to the labor cost and downtime involved in changeout, and since efficiency is actually increased, it is beneficial to use prefilters for as long as possible. They must be periodically inspected, however, because cell deterioration may become a problem with prolonged usage in some cases. Any sudden large variation in pressure drop indicates a potential problem and should be investigated immediately.

Operation at airflow levels <u>below</u> the manufacturer's rated capacity extends filter life and reduces changeout frequency. For this reason an oversized housing (i.e., one designed to hold more filters than required to obtain the system design airflow) should have extra filter cells installed in the mounting frames instead of using blankoff plates. For example, at CAMDS, the 3,000- and 6,000-cfm housings are exactly the same. The actual flow through each prefilter in a 3,000-cfm unit is 500 cfm (50% of its rated capacity of 1,000 cfm) which should extend its life considerably.

4.1.3.2. HEPA Filters

4.1.3.2.1. Definition and Function

A HEPA filter is defined[18] as "a throw-away, extended-media, dry-type filter in a rigid frame having a minimum particle-collection efficiency of 99.97% for 0.3-micron, thermally-generated particles; a maximum clean-filter pressure drop of 1.0 in. wg when tested at its rated airflow capacity; and maximum flow velocity of 5 fpm through any part of its medium when operating at its rated airflow.

The function of the HEPA filter is to remove submicron particulates at extremely high efficiency, preventing their escape to the atmosphere and protecting downstream adsorber cells from becoming clogged or contaminated with particulate matter. Normally, there are two banks of HEPA filters installed in each housing. The first bank, installed between the prefilter and adsorber banks, removes solid particulates and aerosols that penetrate the prefilter. The second HEPA bank, located downstream from the adsorber banks, captures carbon dust escaping from the adsorber media and serves as a backup in case of failure of the first HEPA filter stage.

4.1.3.2.2. Performance and Construction

There are three types of HEPA filters with respect to performance:[18] (1) type A, tested through the filter face for overall penetration (i.e., 100 minus percent efficiency) at rated flow only; (2) type B, tested for overall penetration at rated flow and also at 20% of rated flow to disclose pinhole leaks that do not show up in the 100% flow test; and (3) type C, scanned filters involving a special leaktest.

The most stringent performance requirements are obtained by specifying that the filter units satisfy both types B and C. Figure 4-35 shows several construction details of HEPA filters and table IV-9 lists typical characteristics.[7]

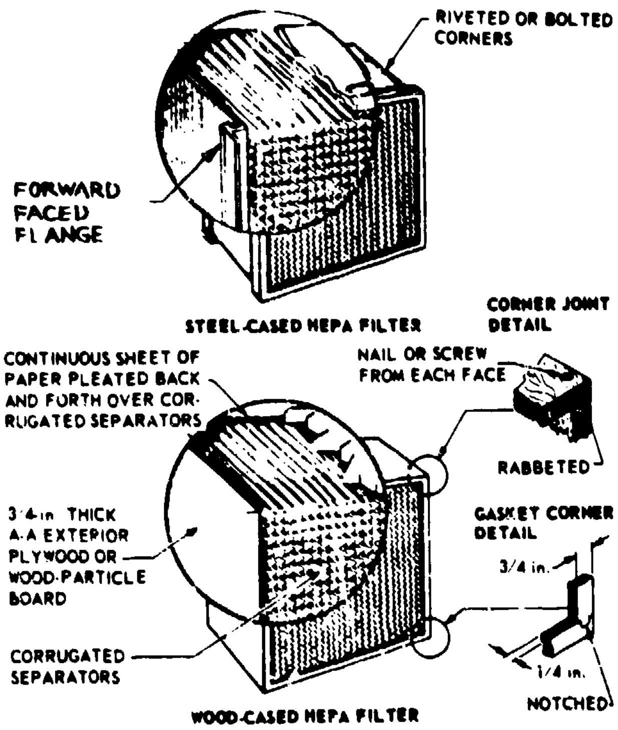


Figure 4-35. Construction Details Of Open-Face HEPA Filters
(Courtesy Of U. S. Department Of Energy)

Table IV-9. Typical Characteristics of Open-Face HEPA Filters[7]

Filter Size (in.)	Nominal Airflow Capacity (a) (cfm)	Approximate Overall Weight of Filter (lb.)	
		Wood Case	Steel Case
8 x 8 x 3-1/6	25	2	3
8 x 8 x 5-7/8	50	3.6	5.8
12 x 12 x5-7/8	125	4.8	7.3
24 x 24 x 5-7/8	500	17	22
24 x 24 x 11-1/2	1000	32	40

(a) These airflow capacities are recommended for design purposes only. Some newer filters constructed to these dimensions are rated at airflows 25 to 50% higher at a maximum pressure drop of 1.0 in. wg.

Construction grades are used to indicate a level of fire resistance and are classified as Grades 1 and 2. Grade 1 is comprised of fire-resistant construction throughout meeting the requirements of UL Standard 900[17]; Grade 2 is semicombustible with noncombustible media; separators, frame, or both are made from combustible material.

Consult references 7, 18, 20, and 21 for additional details on the performance and construction of HEPA filters.

4.1.3.2.3. Selection

For logistical reasons, HEPA filters of standard design are generally preferred. However, the important advantage of simplified installation may be of overriding consideration even if it involves the disadvantage of a special filter design. For this reason, a special-type filter with sealing flange on one face only was specified for use at CAMDS (figure 4-36). This design permits "bayonet" type installation, with sealing at the backside of the flange as depicted in figures 4-22, 4-37, and 4-38. The HEPA filter meeting this requirement and finally selected for CAMDS was SUPER-FLOW ® Model 7081-NL filter manufactured by Flanders Filters, Inc., Washington, North Carolina. This specific model was chosen primarily because it offers the desired flanging configuration for incorporation into the clamping arrangement designed by the filter housing manufacturer.

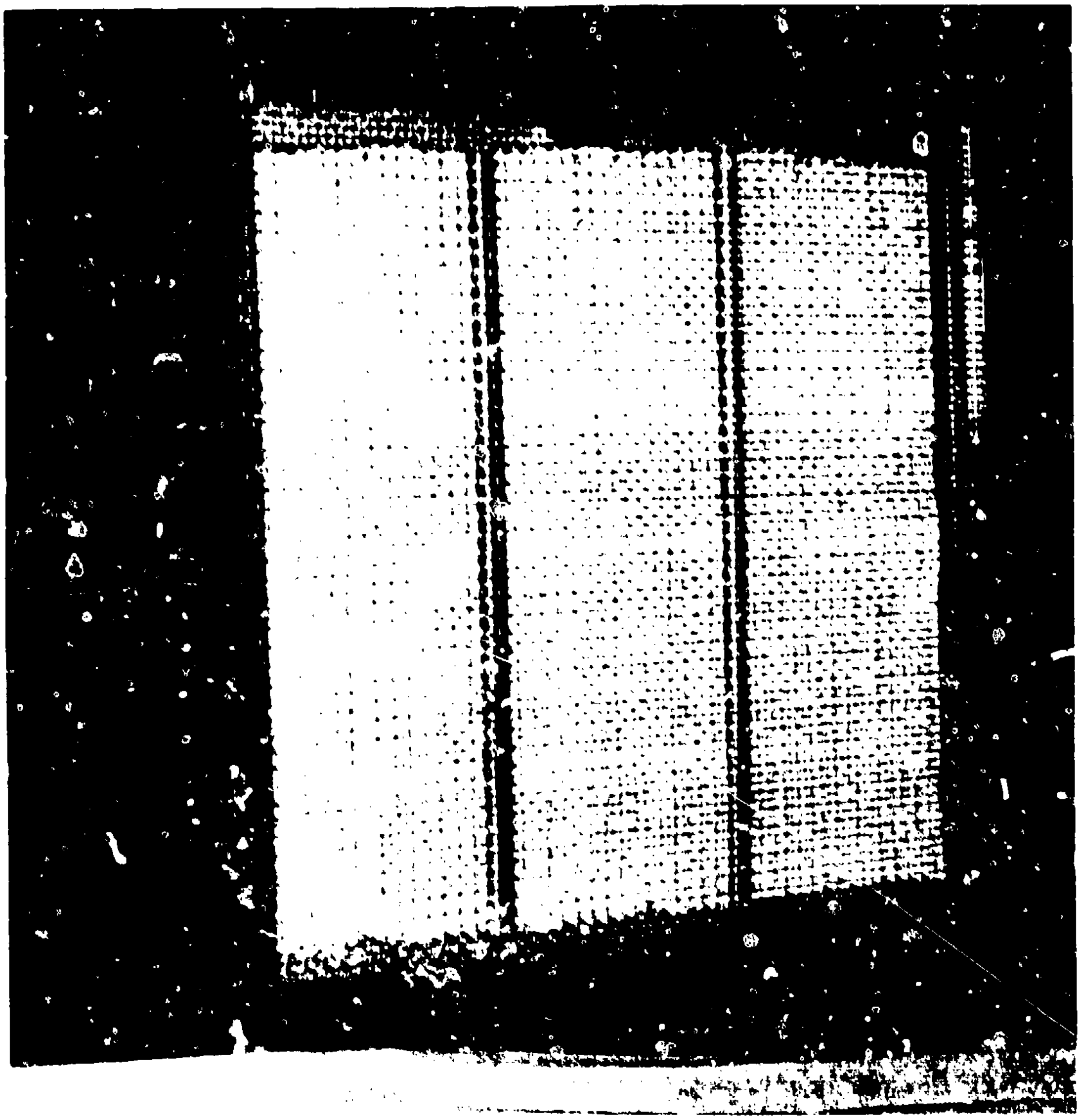


Figure 4-36. Type of HEPA Filter In Use At CAMDS

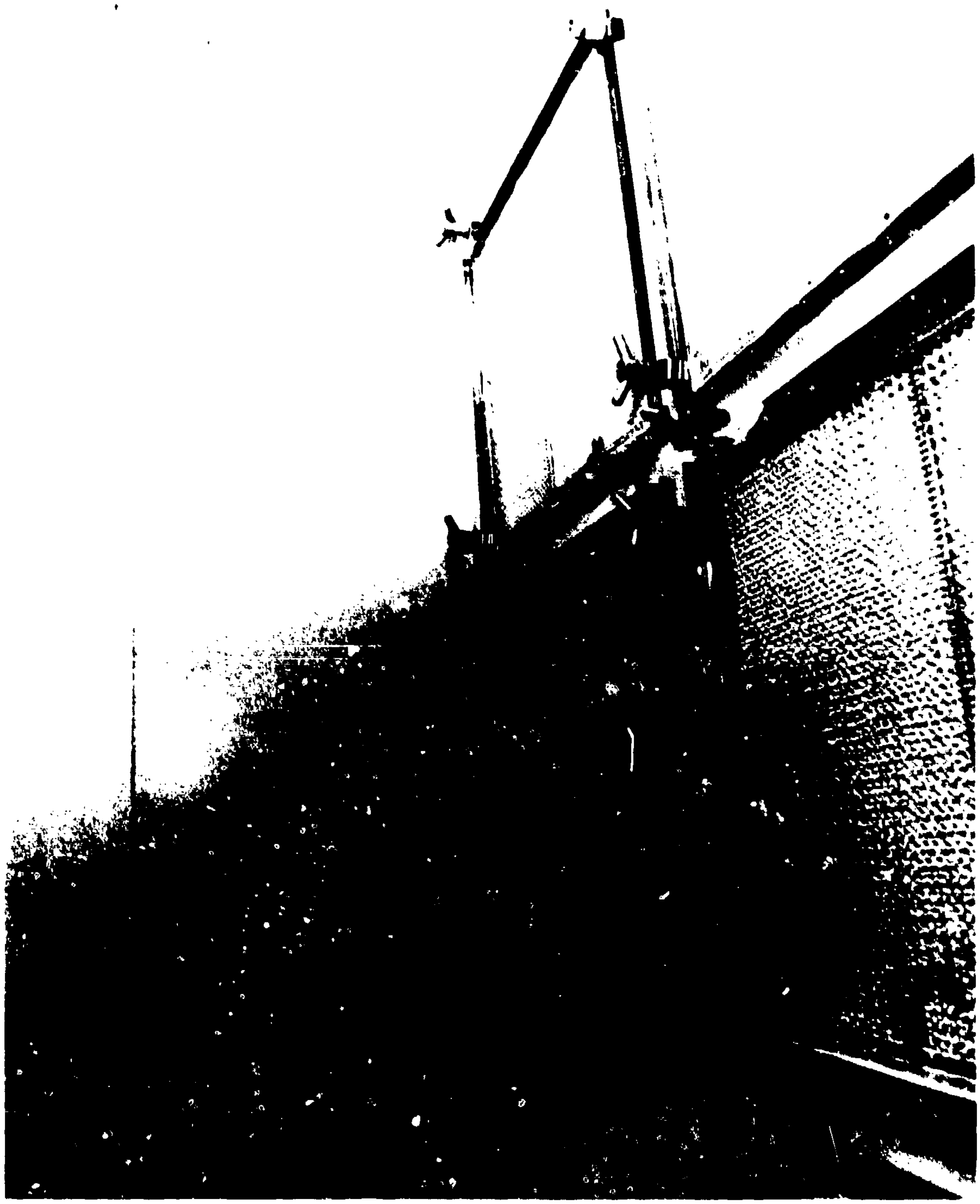


Figure 4-37. Front View Of HEPA Filter Bank Installed In Type II Filter System At CAMDS. Sealing Surface Of Filter Is In Rear Of Front Flange

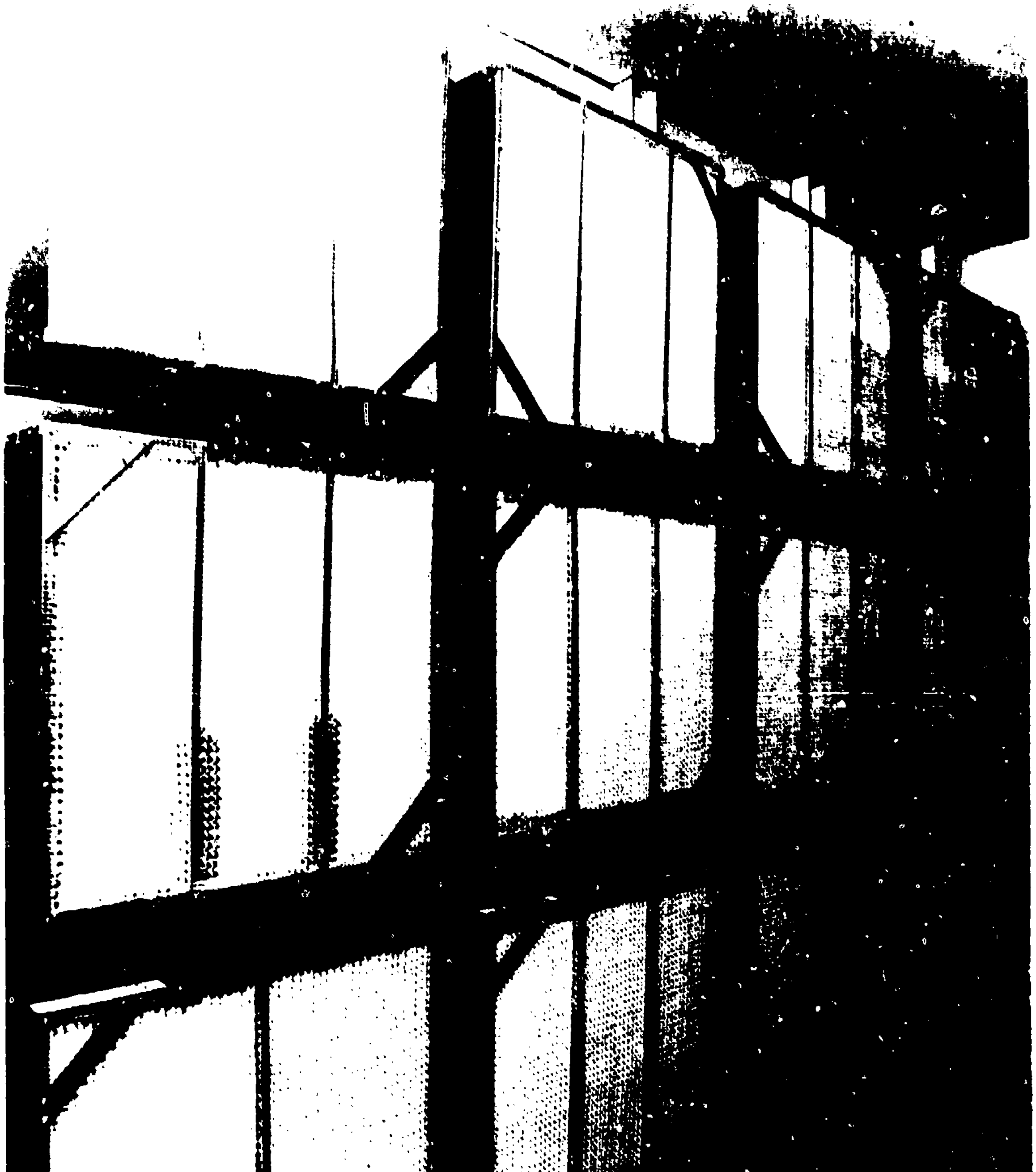


Figure 4-38. Rear View Of HEPA Filter Bank Installed In Type II Filter System (12,000 Cfm) At CAMDS

The filter was obtained by specifying the type, class, group, and efficiency and then allowing the filter housing manufacturer (CTI-Nuclear, Inc., Denver, Colorado) procure it. The Model 708-NL filter is classified as Grade 1 meeting type B and type C requirements of AACC CS-1,[18] with steel frames and no separators. It is rated at 1,500 cfm and measures a standard 24 in. x 24 in. x 11-1/2 in.

The SUPER-FLOW model was selected because of its advertised capacity of 1,500 cfm (as compared to 1,000 cfm for the regular model). Since the ventilation system is designed for only 1,000-cfm airflow through each filter cell, it is expected that the SUPER-FLOW units, by operating at less than capacity, will last significantly longer than the regular model.

Critical pressure-drop values supplied by the manufacturer for the Model 7081-NL HEPA filter are as follows:*

1. Normal operating differential pressure for 1,500 cfm, 1.2 in. wg.**

2. Recommended differential pressure for changeout, 3.0 to 4.0 in. wg.

3. Maximum pressure differential at which HEPA filter can be safely used, 10.0 in. wg.

4.1.3.2.4. Installation

For HEPA filters in the CAMDS units, all framing and support equipment were furnished by the housing manufacturer as an integral part of the filter housing (figures 4-22, 4-37, and 4-38). HEPA filter mounting frames are designed for horizontal airflow. For ease of maintenance, the mounting frames in type II housings limit all parts of the filter installation to a maximum height of seven feet above the walking surface. Each filter is independently clamped in place at a minimum of four pressure points with the pleats running vertically. Common bolting at four pressure points is also acceptable although it was not used at CAMDS.

Filters are mounted on the downstream side of the mounting frames since there is less contamination of the filter casing on this side.

*Actual differential pressure experienced at CAMDS for clean HEPA filters at rated airflow ranged from about 0.7 to 1.0 in. wg.

**The manufacturer recently changed the applicable pressure for this rating from 1.0 in. wg to 1.2 in. wg.

4.1.3.2.5. Visual Inspection

The following visual inspections should be made of HEPA filters before and after installation:

1. HEPA Filter

   a. Damage to or deterioration of shipping carton. This is the first indication of shipping and/or storage damage. If found, the enclosed filters should be closely examined for possible damage or deterioration.

   b. Damage to media, case, or gaskets.

   c. Proper identification.

   d. Adherence to specification requirements.

   e. Installed with pleats vertical.

2. Mounting Frames

   a. Squareness of members, flatness, and condition of component seating surfaces.

   b. Continuous seal-weld between members of frame and between frame and housing. (Sealant must not be used in these areas.)

   c. Structural rigidity.

   d. Damage to frames.

3. Clamping Devices

   a. Proper adjustment (50 to 80% gasket compression all around; tighten if less).

   b. Sufficient number of clamping points (at least four per filter) and adequate size to produce uniformity of gasket compression.

   c. Proper condition of clamping devices (e.g., all nuts in place and tightened).

d. Adequate clearance between filters to grasp them and to tighten clamping devices on all sides.

e. High quality welds and freedom from cracks.

4.1.3.2.6. Changeout Frequency

After installation, pressure drop (or resistance) is the primary factor in HEPA filter replacement. The HEPA filter is instrumented with a differential pressure gage to measure the pressure drop across the filter bank. A large increase in differential pressure indicates the filter cell is becoming plugged and requires changeout. A decrease in differential pressure indicates the filter has a hole, tear or leak which also requires corrective action. It is recommended that the pressure drop be checked and recorded daily to provide a history of differential pressure data as a guide for future operation and servicing.

Changeout should occur when the maximum allowable pressure drop suggested by the manufacturer is reached. A key factor in determining changeout time is the ability of the fan to maintain the required flow at the higher ΔP. If the fan is sufficiently oversized and the filters are capable of withstanding the overpressure, changeout can occur at a higher value rather than the recommended value. The manufacturer's recommended value is not necessarily when filter efficiency decreases, but rather the point above which the filter will clog up (i.e., increase its ΔP) at a much faster rate for a given amount of contamination retained.

As HEPA filters partially clog due to a buildup of contamination on their surfaces, some types (including those used at CAMDS) become more efficient. Since the replacement cost of the filter itself is minimal compared to the labor cost and downtime involved in changeout, and since efficiency is actually increased, it is beneficial to use HEPA filters for as long as possible. They must be periodically inspected, however, because cell deterioration may become a problem with prolonged usage in some cases. Any sudden large variation in pressure drop indicates a potential problem and should be investigated immediately.

Operation at airflow levels below the manufacturer's rated capacity extends filter life and reduces changeout frequency. For this reason an oversized housing (i.e., one designed to hold more filters than required to obtain the system design airflow) should have extra filter cells installed in the mounting frames instead of using blankoff plates. For example, at CAMDS, the 3,000 and 6,000-cfm housings are exactly the same. The actual flow through each HEPA filter in a 3,000-cfm unit is 500 cfm (33% of its rated capacity of 1,500 cfm) which should extend its life considerably.

No excess HEPA filters are installed in the second bank, only the required amount (i.e., three blankoff plates are used in the 3,000-cfm units) since it is anticipated that very little contamination will reach this bank. Therefore, changeout of the HEPA filters in the second bank will be based on total life rather than on level of contamination.

Refer to section 6.4 for additional information on filter replacement.

4.1.3.3. Adsorber Cells

4.1.3.3.1. Description

Adsorber cells consist of two beds containing an adsorbent, such as activated carbon, used for removing contaminant gases or vapors from the air.

The types of adsorber cells considered for chemical demil operations are intended for very high-efficiency air-cleaning service and not for common industrial applications. Adsorber cells for this purpose are classified as (1) type I pleated-bed units (previously used in the nuclear field but now becoming obsolete); (2) type II modular type units (now used extensively in the nuclear field), which meet the design, dimensional, filling, and test requirements of AACC CS-8[10]; and (3) type III stationary gasketless adsorbers (also known as Permanent Single Units), permanently installed units in which only the adsorbent is changed; it is a relatively new concept. Since the type I unit is on the verge of obsolescence for high-efficiency applications, this discussion is limited to type II and type III stationary adsorber versions.

4.1.3.3.1.1. Type II Adsorber Cell

The type II high-efficiency, gas-phase adsorber cell is defined[10] as a modular container for an adsorbent with provisions for sealing to a mounting frame for use singly or in multiples to construct a system of a specified airflow capacity. It is a flat-bed or tray-type configuration as shown in figures 4-39, 4-40, and 4-41. At present, the cell is considered as disposable for CAMDS use after removal from service, even though it is designed for refill; the economics of refill and reuse are being investigated at CAMDS.

The type II adsorber cell consists of two individual parallel adsorbent beds, nominally two inches thick, spaced approximately two inches apart. The beds are enclosed by a nonperforated casing on three sides and a solid face plate, except for the air slot, with a neoprene gasket on the fourth side. Covering the top and bottom of each half are perforated screens of No. 26 US Standard gage with a 30% minimum open area.

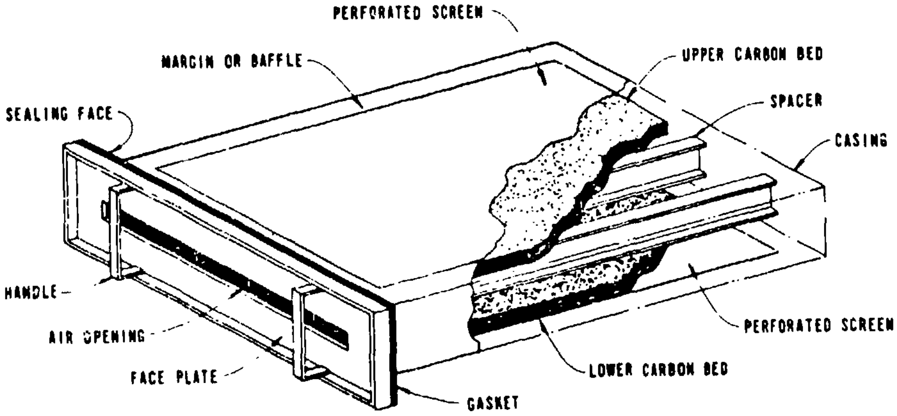


Figure 4-39. General Configuration Of Type II Adsorber Cell (Tray Type) (Courtesy Of U. S. Department Of Energy)

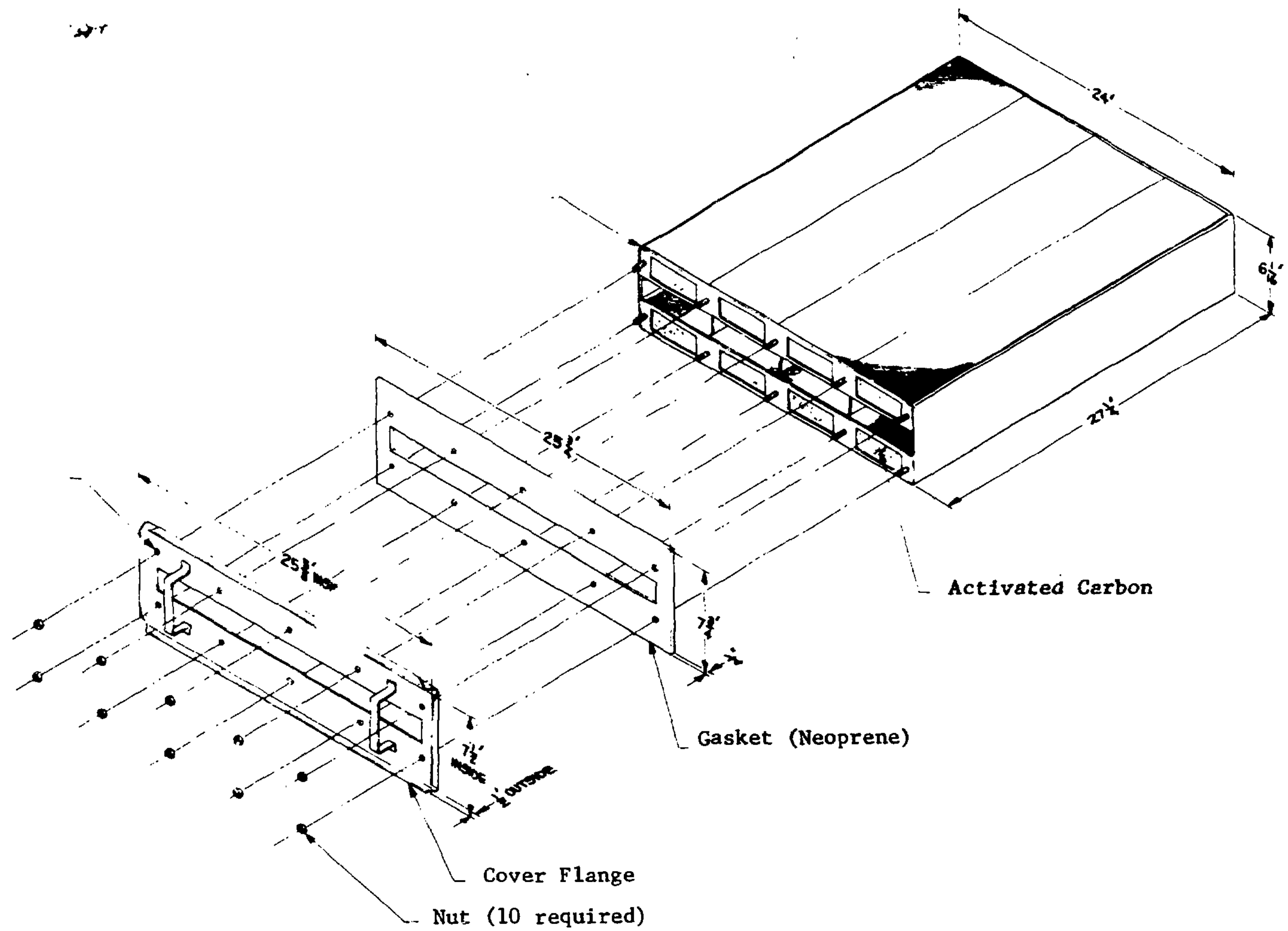


Figure 4-40. Configuration Of Type II Adsorber Cell (Tray Type) Used At CAMDS (Courtesy Of CTI-Nuclear, Inc.)

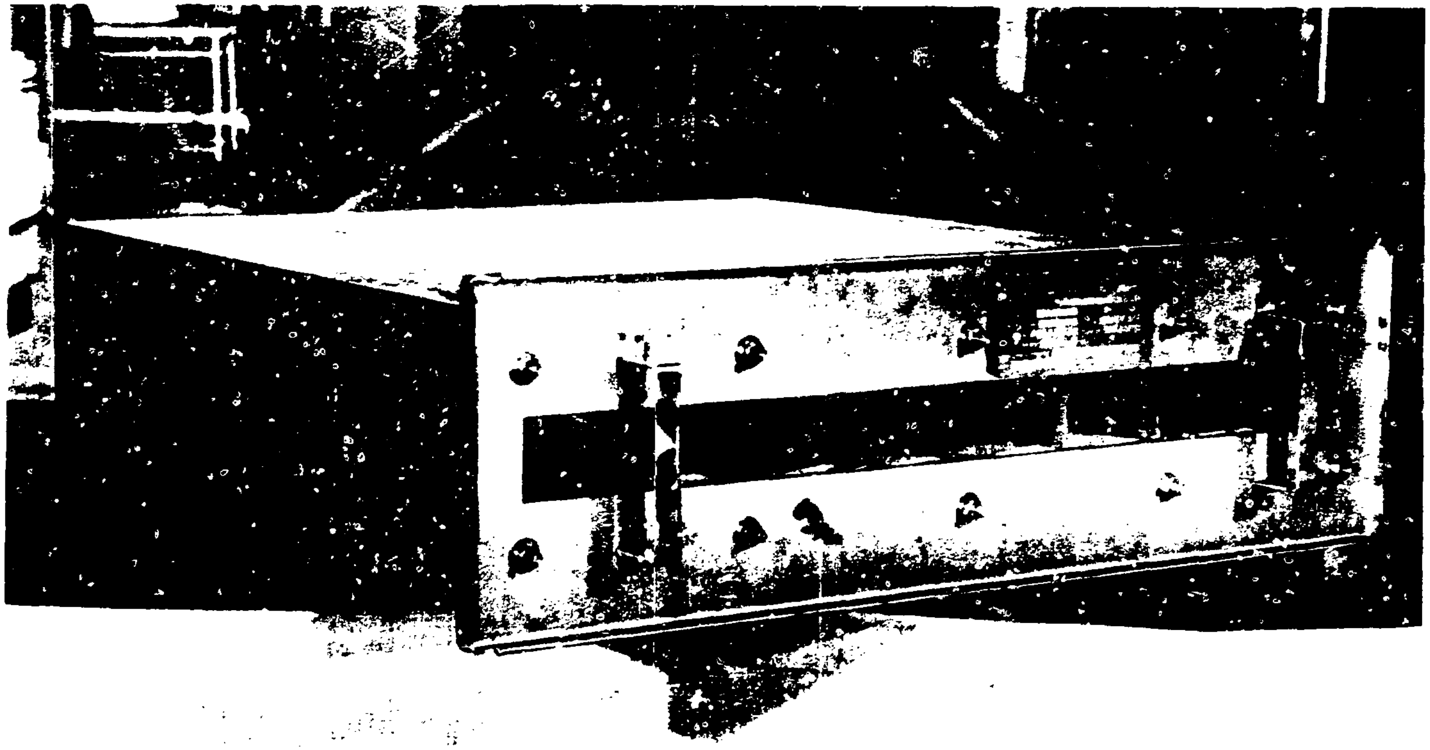


Figure 4-41. Type II Adsorber Cell (Tray Type) Used At CAMDS

The face-plate and cross-sectional dimensions are established by AACC CS-8.[10] The length of the cell varies, according to the manufacturer's particular design, from 26 to 32 in. The weight of the cell ranges between 80 and 100 pounds, depending on the design, of which 47 to 65 pounds are activated carbon. No caulking, scrims, or other nonmetallic materials, except neoprene gaskets, are permitted in its construction.

4.1.3.3.1.2. Type III Stationary Adsorber

The type III adsorber is basically a single unit permanently installed within the filter housing and seal-welded to the inner housing wall. Since this concept requires that only the adsorbent be added or removed, the beds are inclined or vertically mounted to permit gravity flow of adsorbent to the extraction port (see figure 4-42). Emptying of the adsorbent may also be accomplished by suction or pneumatically. Both filling and unloading operations can be performed from outside the filter housing.

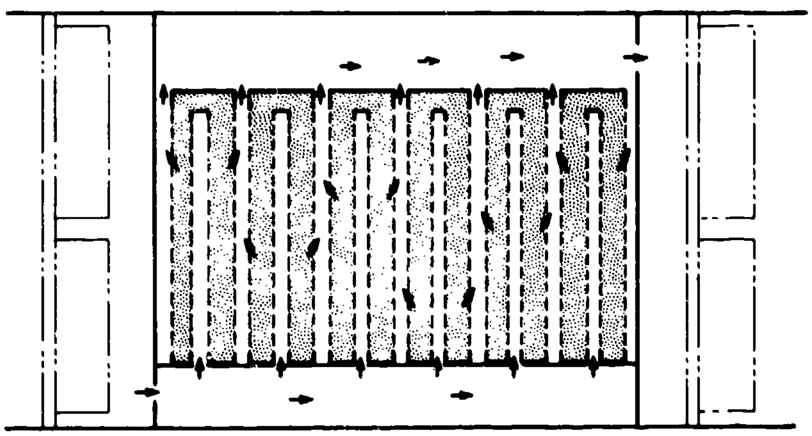
Uniform bed packing-densities can be realized with the type III concept. The creation of voids by the settling of adsorbent is eliminated by topping off the bed with additional adsorbent located in a common fill reservoir on top of the assembly. While bed depth and perforated screen size are varied to meet specific system requirements, they are usually based on the same criteria as the type II cells. Techniques have been developed in the nuclear industry for removing contaminated adsorbent from the type III cell and loading it directly into a disposal drum without danger of releasing contamination to the atmosphere.

The main advantage of the type III concept is the potential savings in both labor and material when the adsorbent is changed. Expensive cell casings do not have to be removed and discarded. The larger the system the greater the savings; this is particularly true if the modular type II units are to be discarded.

There are potential disadvantages to the system, however. First is its newness. The permanent adsorber concept had just been developed when the CAMDS specifications were prepared and thus was not considered for inclusion. To date, there is still no standard covering this system, although such action is underway by a committee of the ASME.

A second disadvantage is that the type III adsorber has never been used in a demil application and, unlike the type II concept where individual trays can be tested, the only way to evaluate it is to test an entire unit. A possible problem area is difficulty in removing contaminated adsorbent saturated with moisture, since the granules tend to stick together. This problem should not occur in most demil applications and should be readily solved by suction techniques if it does arise.

a. View of Downstream Face of Inclined-Bed PSU Adsorber



b. Airflow Through Typical Vertical-Bed PSU Adsorber

Figure 4-42. Type III Stationary Adsorber
(Courtesy of U. S. Department of Energy)

4.1.3.3.1.3. Materials of Construction

Adsorbers are subclassified by the material of construction. These classes and materials are:

Class A: type 304 stainless steel, ASTM A167[22] (alternate, ASTM A240).[23]

Class B: type 409 stainless steel, ASTM A176.[24]

Class C: carbon steel with epoxy coating.

4.1.3.3.2. Selection

The adsorber cell selected for CAMDS use was a type II class A unit manufactured by CTI-Nuclear, Inc., Denver, Colorado, and designated Model No. CS-800. The adsorbent contained in this cell is described in section 4.1.3.3.6.

The Model CS-800 unit is rated at 333 cfm. It is a standard size (see figure 4-40 for dimensions) in accordance with AACC CS-8[10]; three of these cells occupy the same frontal area as one HEPA filter or prefilter. The cell is designed for a gas residence time of 0.25 second and a maximum pressure drop of 1.25 in. wg when operated at its rated airflow.

Class A construction was specified to provide a corrosion-resistant casing due to the lack of information on the potential corrosiveness of the airstream. Corrosion can result when certain corrodents in the airstream (e.g., NO_x) plus moisture combine within the adsorbent to affect the enclosing cell surfaces. Since the same manufacturer designed both the mounting frame (also standardized per AACC CS-8) and the cell frame there was no problem of incompatibility with the clamping mechanism.

4.1.3.3.3. Installation

All necessary framing and support equipment for type II adsorber cells is furnished as an integral part of the filter housing (figures 4-17 and 4-21). The cabinet drawer-like adsorber mounting frames are designed for horizontal airflow and sized in accordance with AACC CS-8.[10] Horizontal mounting avoids settling and resultant leakage around and above the adsorbent bed. Airflow can be in either direction, which means the cell can be mounted with its air opening (in the faceplate) facing upstream or downstream.

The rear surface of the faceplate of each adsorber cell may be independently clamped and sealed to the mounting frame at a minimum of four pressure points. Common bolting of adsorber cells is acceptable in demil applications and is being used at CAMDS. For ease of maintenance, the mounting frames of the walk-in housings should not extend more than seven feet above the walking surface.

4.1.3.3.4. Visual Inspection

The following visual inspections should be made of the adsorber cells before and after installation:

1. Adsorber

   a. Damage to or deterioration of shipping carton. This is the first indication of shipping and/or storage damage. If found, the enclosed adsorbers should be closely examined for possible damage or deterioration.

   b. Damage to media, case, or gaskets.

   c. Excessive carbon fines or loose adsorbent.

   d. Proper identification.

   e. Adherence to specification requirements.

2. Mounting Frames

   a. Squareness of members, flatness, and condition of component seating surfaces.

   b. Continuous seal-weld between members of frame and between frame and housing. (Sealant must not be used in these areas.)

   c. Structural rigidity.

   d. Damage to frames.

3. Clamping Devices

   a. Proper adjustment (50 to 80% gasket compression all around; tighten if less).

   b. Sufficient number of clamping points (at least four per adsorber) and adequate size to produce uniformity of gasket compression.

c. Proper condition of clamping devices (e.g., all nuts in place and tightened).

d. Adequate clearance between adsorbers to grasp them and to tighten clamping devices on all sides.

e. High quality welds and freedom from cracks.

4.1.3.3.5. Changeout Frequency

Although the CAMDS adsorber banks are instrumented with differential pressure gages, pressure drop is not a factor in adsorber replacement. The actual changeout of the adsorber cells in the first bank is based upon readout of the agent monitor located between the two adsorber banks.

Refer to section 6.4 for additional information on adsorber replacement.

4.1.3.3.6. Adsorbent

The adsorbent is the material in the adsorber cells which removes gases or vapors from the airstream to prevent their escape into the atmosphere. Agent capture is accomplished by physically retaining the gaseous molecules or, if the adsorbent is impregnated, by chemical reaction, depending upon the type of chemical agent involved. The adsorbent shall be coal-base or coconut-base activated carbon meeting the specifications listed below.

Specification	Value	Test Used
Iodine Number, Minimum*	1,000	MIL-C-13724[25]
Carbon Tetrachloride Adsorption, Minimum, % Weight*	59	ASTM D2652[26]
Ash, Maximum, %	8.0	MIL-C-13724
Total Volatiles (150°C ± 50°C for 3 hours), %	4.0	MIL-C-13724
Hardness Number, Minimum	90	MIL-C-13724
Apparent Density (Bulk Density, Dense Packing), Minimum, g/cc	0.48	MIL-C-13724
Packed Column Test (To determine maximum total capacity of GB agent retained on adsorbent), Minimum, grams agent/grams adsorbent.	0.4	CSL in-house test plan

*Both of these tests are not required. The Carbon Tetrachloride Adsorption Test is preferred but the Iodine Number Test may be run as an alternative.

Particle Size (3-Minute Shake Test): ASTM D2862[27] and ASTM E323[28].

Sieve Size	Percent Retained
8 Mesh	0.5
8 x 12 Mesh	35-65
12 x 16 Mesh	35-65
16 Mesh	(through) 1-5

Both coal-base and coconut-base activated carbons are used at CAMDS. The initial lots (no. ElG, E36, and 63G) were procured from Westvaco (coal-base), while a later lot (no. 0906, Type 512) was supplied by Barneby Cheney Co. (coconut-base).

Refer to Appendixes B and C for additional detailed information pertaining to adsorbent technology and general characteristics of activated carbon, respectively.

4.2. Ventilation System Design Criteria

This section presents design criteria and guidelines for planning the air-ventilation system to be served by the filter/adsorber system described earlier. Design information is provided on hoods, ducts, airlocks, fans, dampers, ancillary equipment, and other pertinent factors.

At this point, a review of various ventilation design considerations based on CAMDS experience might be helpful.

1. If the demil operation is such that agent release at low concentrations is likely in routine operations and there is a possibility of high concentrations under upset conditions, containment should be provided by the following techniques:

   a. Surround the area by a toxic enclosure. Entry to and exit from the toxic enclosure should be through a double-door airlock with decontamination shower. The toxic enclosure should be constructed inside an outer enclosure to prevent wind pressure from bearing directly on the walls of the toxic enclosure. A building with coverings on both the outside and inside of the framing can simultaneously provide outer and inner enclosures. The internal surfaces of the toxic enclosure must be free from cracks or crevices and be easily decontaminated.

   b. Toxic enclosures should be ventilated with sufficient airflow to provide at least 0.1 in. wg negative pressure with respect to the atmosphere. The amount of airflow required to obtain the specified negative pressure depends on how well the building is sealed; the greater the leakage, the greater the amount of ventilation required.

   c. If any operation within a toxic enclosure is likely to produce relatively high vapor concentrations or expose liquid agent, localized exhaust ventilation must be provided to contain the contamination in the smallest area possible.

2. If the operation is such that agent release even at low concentrations is possible but unlikely, the area shall be sufficiently ventilated to assure minimum continuous airflow.

At CAMDS all toxic enclosures are within an outer enclosure that protects against wind effects. The toxic enclosure areas (work rooms) are designed for 0.10 to 0.15 in. wg negative pressure. Actual testing by AEHA indicated that at least one area, the ECC, actually maintained 0.3 in. wg negative pressure. No hydraulic or pneumatic mechanisms are required to open doors in any of the negative pressure facilities of CAMDS.

4.2.1. Hoods

There are three major types of exhaust hoods: (1) enclosing hoods, (2) capturing hoods, and (3) receiving hoods. Enclosing hoods surround toxic-gas operations as completely as possible, with openings limited to those needed to provide access to perform the operation. Capturing hoods are shaped inlets designed to capture contaminated air, while receiving hoods control processes that throw a stream of contaminants in a specific direction. Receiving hoods are normally not used for highly toxic materials and therefore are not discussed here. Since local-exhaust systems require that hoods retain or capture contaminants, hood design and location are critical in making the ventilation system work properly.

4.2.1.1. Enclosing Hoods

Contaminants are retained in enclosures by air flowing through the openings. Face velocity is an important parameter in this regard. The face velocity must be adequate to prevent crossdrafts or other room air currents from drawing contaminants out of the hood. For chemical agents a minimum inward velocity of 150 fpm is required. If enclosures are used to control processes where agent is actively generated by heat or mechanical agitation, the openings should be away from the path of contaminant travel, and the inward face velocities should be 200 to 500 fpm. Enclosure openings should be located away from sources of crossdrafts which have a velocity that might exceed 20 percent of the hood-face velocity.

The quantity of air handled is calculated by multiplying the face velocity by the area of the openings, that is:

$$Q = V \times A \qquad (1)$$

where:

Q = airflow volume, cfm
V = face velocity, fpm
A = area of hood opening, ft^2

The more complete the enclosure, the more economical and effective the installation will be. Openings are kept to a minimum by providing access to the operation through glove ports and windows for observation. See figure 4-43.

Two other considerations in selecting airflow are: (1) temperature increase if a heat source is enclosed, and (2) maintaining the concentration of combustible gases or aerosols below the lower explosive limit (LEL). If air expands due to heat after it enters the hood, a large volume of air must be exhausted to maintain the face velocity selected.[4] To calculate the flow necessary to maintain concentration below LEL, use the formula:

$$\frac{\text{cubic feet of air}}{\text{pounds of material evolved}} = \frac{(387)(100)(C)}{(\text{molecular weight})(B)(LEL)} \qquad (2)$$

where:

C = safety factor representing excess air to dilute below LEL; usual value is 4.

B = collection factor for high temperature
= 1 $\leq 250^{o}F$
= 0.7 $> 250^{o}F$

Refer to reference 4 (pages 2-1 and 2-2) for background information regarding the above formula.

4.2.1.2. Capturing Hoods

Capturing hoods are less effective than enclosing hoods because control is easily disrupted by crossdrafts. They are recommended only when it is impossible to enclose the operation. Airflow through capturing hoods must be adequate to achieve the desired capture velocity, and it must be distributed over the entire zone into which contaminant is being generated. To be effective, capturing hoods must be close to the operation serviced, within at least two feet.[4]

For chemical agents, the capture velocity must be at least 150 fpm, and 200 to 500 fpm if agent is being actively generated. Airflow through the hood is based on the capture velocity selected and the distance of the hood from the operation. The equations used are listed in table IV-10. Proper distribution of capture velocity is achieved by adding flanges, slots, or splitter vanes, and by tapering the hood (see sidedraft and suspended hoods shown in figure 4-44). Flanges improve the efficiency of hoods by causing air to be drawn more from the front of the hood. Slots in a plenum chamber distribute air uniformly if (1) slot velocity is twice plenum velocity, and (2) slot width does not exceed 20 percent of slot length. Splitter vanes channel airflow to different parts of the hood. A gradual taper allows air to be drawn in from the entire hood face.

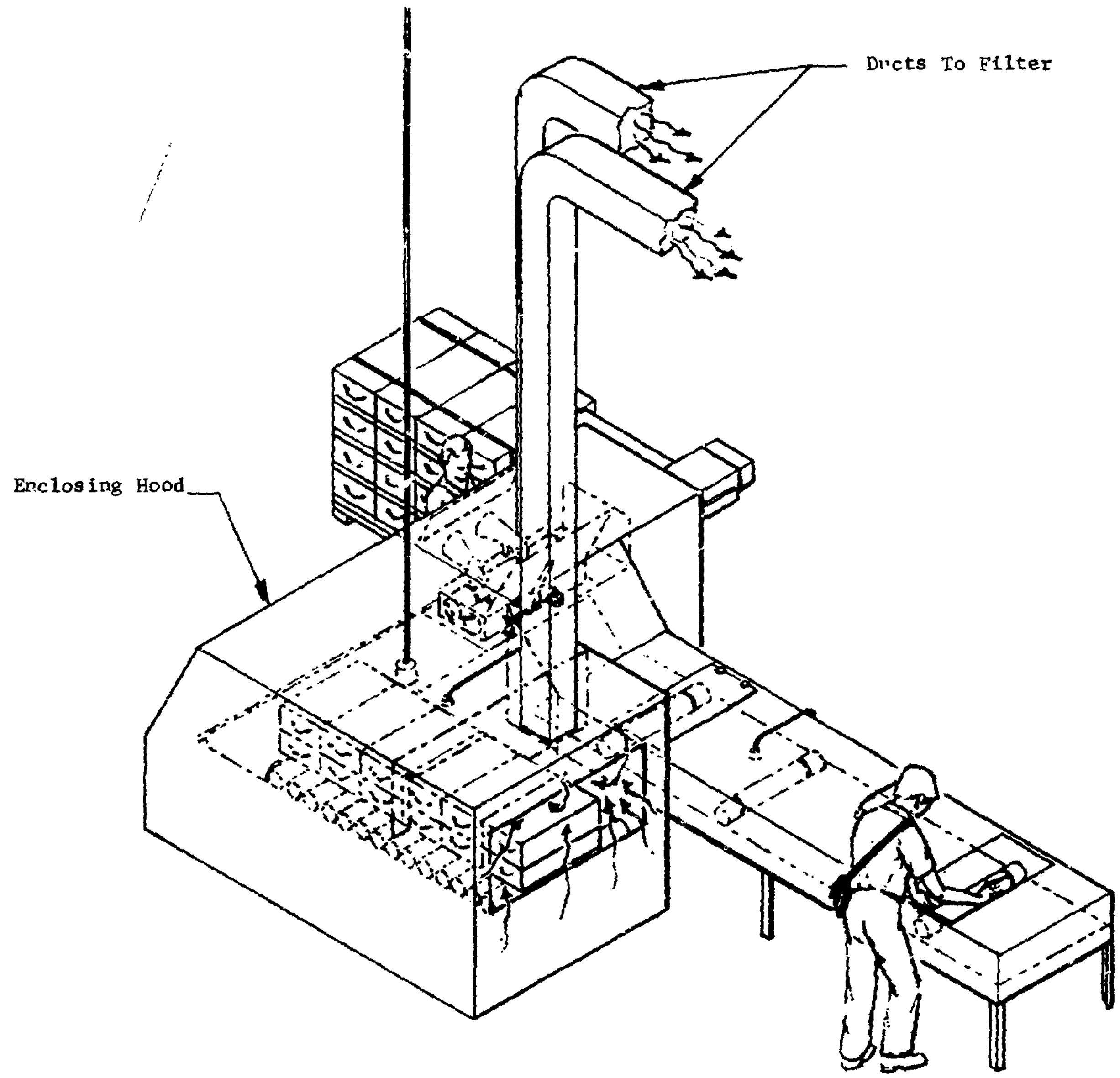
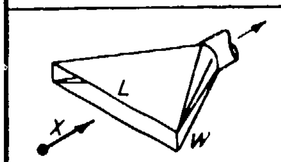
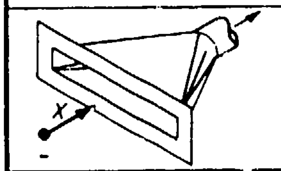
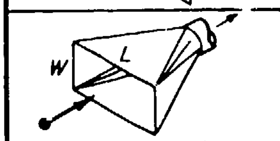
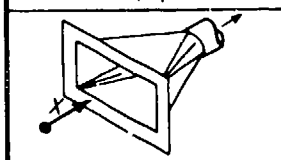
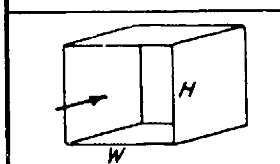
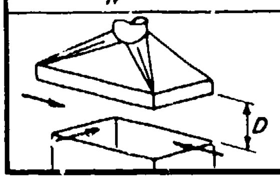


Figure 4-43. Example Of An Enclosing Hood

Table IV-10. Formulas For Calculating Airflow Through Capturing Hoods (Courtesy Of American Conference Of Governmental Industrial Hygienists)

HOOD TYPE	DESCRIPTION	ASPECT RATIO, $\frac{W}{L}$	AIR VOLUME
	SLOT	0.2 or less	$Q = 3.7\,LVX$ (Reference 38)
	FLANGED SLOT	0.2 or less	$Q = 2.8\,LVX$ (Reference 38)
 $A = WL$ (sq. ft.)	PLAIN OPENING	0.2 or greater and round	$Q = V(10X^2 + A)$ (Reference 9)
	FLANGED OPENING	0.2 or greater and round	$Q = 0.75\,V(10X^2 + A)$ (Reference 9)
	BOOTH	To suit work	$Q = VA = VWH$
	CANOPY	To suit work	$Q = 1.4\,PDV$ See VS-903 P = perimeter of work D = height above work

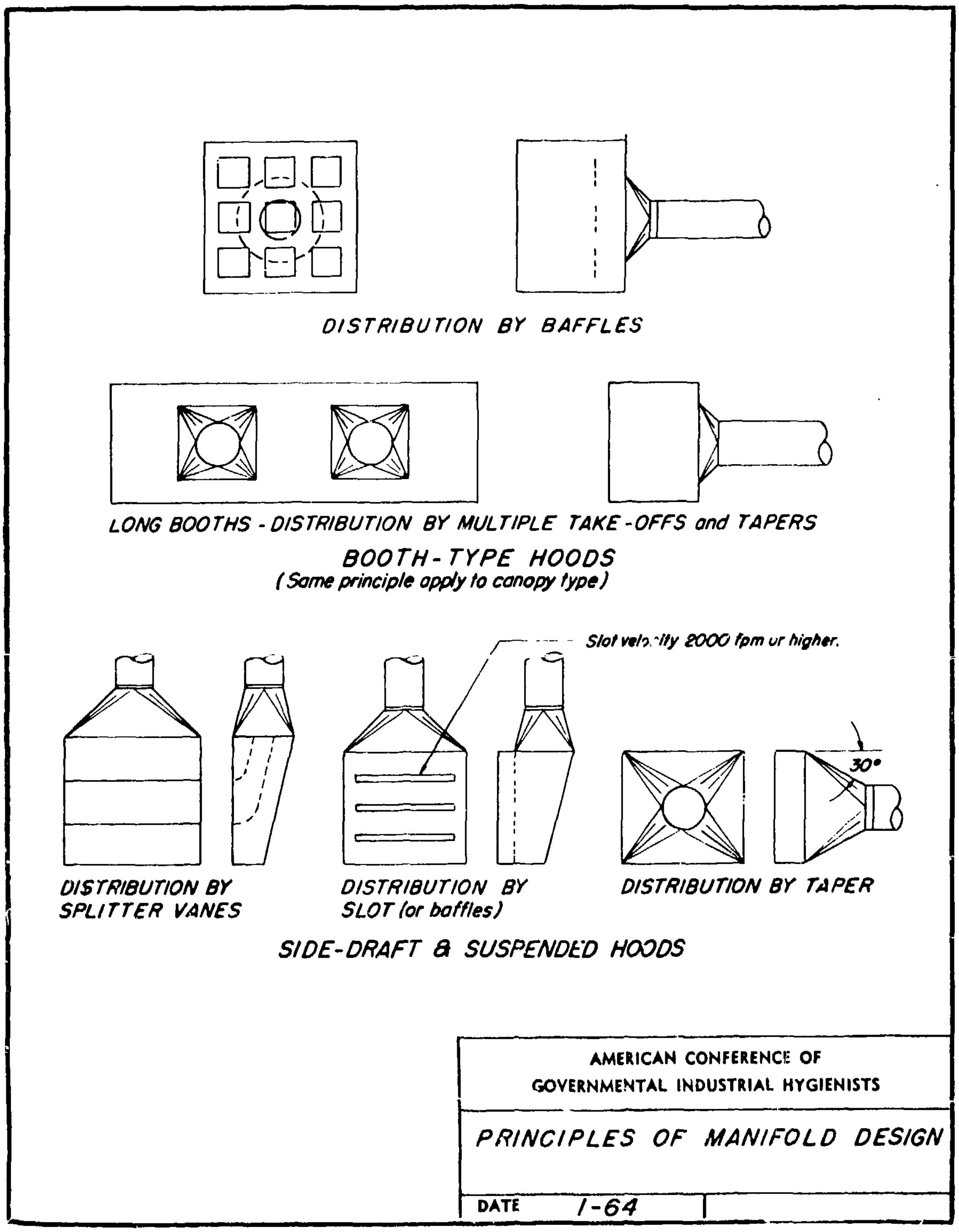


Figure 4-44. Principles Of Manifold Design For Capturing Hoods (Courtesy Of American Confe nce Of Governmental Industrial Hygienists)

The included taper angle should be about 30° but not greater than 60°. See reference 4 for a more extensive discussion of capturing hoods.

4.2.2. Duct Design

This section outlines a method for designing the ductwork for air-ventilation systems. The first step is to lay out those operations to be locally exhausted and those areas that require general exhaust ventilation, then develop data on each hood as to airflow requirements, entry loss, minimum duct velocity, and the negative pressure to be maintained in regulated areas. Hood entry loss has two components: (1) acceleration loss and (2) turbulence loss (figure 4-45). The acceleration loss is equal to the velocity pressure of the air stream when it reaches duct velocity. Velocity pressure is calculated using the equation:

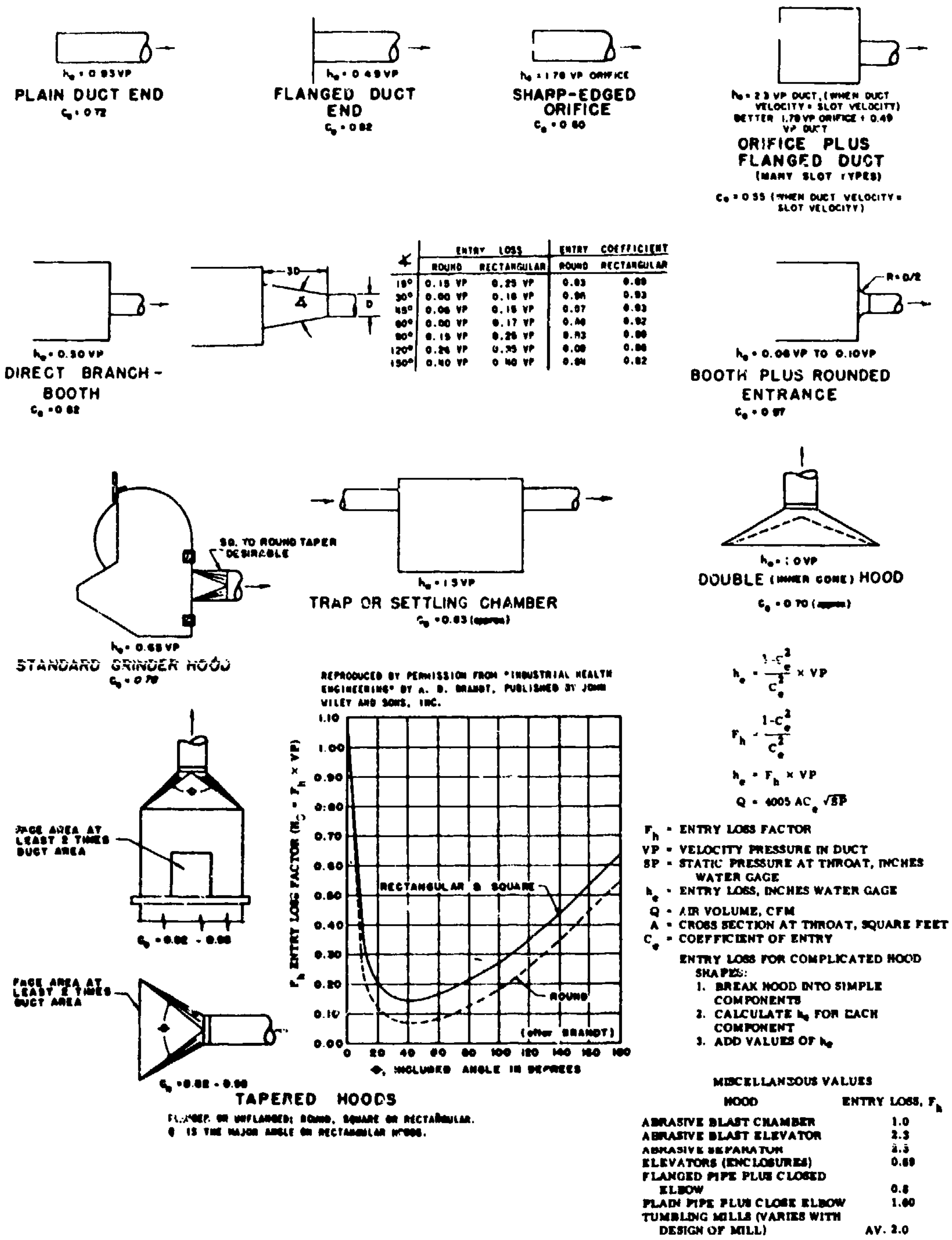
$$VP = \left(\frac{V}{4005}\right)^2 \tag{3}$$

where:

VP = velocity pressure, in. wg
V = air velocity in duct, fpm

Duct velocity is established by sizing the duct ($V = Q/A$) in accordance with reference 4. Systems that handle dusts or mists require a minimum transport velocity to prevent material from settling in the ducts. Reference 4 provides minimum duct velocities for many materials. For systems that handle gases, duct velocities between 2,000 and 3,000 fpm are usually selected as a compromise between construction costs and fan operating costs (i.e., relative to the ΔP seen by the fan). Since vapor contamination is the main problem at CAMDS, a transport velocity of 1,800 to 2,000 fpm was established as a design criterion. Turbulence losses encountered by air as it enters the hood and other system components are a function of velocity and directly proportional to velocity pressure. Hood entry loss factors are listed in reference 4.

The duct system consists of a number of branch ducts connected to the main duct for conveying the air from the hoods to the filter when local exhaust ventilation is used. When general ventilation is used, the duct system consists of branch ducts connected to a main duct for conveying the air from different sectors of an area to the filter. There are basically two types of duct systems: (1) balanced system without blast gates, and (2) balanced system with blast gates.



∢	ENTRY LOSS ROUND	ENTRY LOSS RECTANGULAR	ENTRY COEFFICIENT ROUND	ENTRY COEFFICIENT RECTANGULAR
15°	0.15 VP	0.25 VP	0.93	[illegible]
30°	[illegible] VP	0.16 VP	[illegible]	0.93
45°	0.06 VP	0.15 VP	0.97	0.93
60°	[illegible] VP	0.17 VP	[illegible]	0.92
90°	0.15 VP	0.25 VP	0.93	[illegible]
120°	0.26 VP	0.35 VP	[illegible]	[illegible]
150°	0.40 VP	0.40 VP	[illegible]	0.82

HOOD	ENTRY LOSS, F_h
ABRASIVE BLAST CHAMBER	1.0
ABRASIVE BLAST ELEVATOR	2.3
ABRASIVE SEPARATOR	1.5
ELEVATORS (ENCLOSURES)	0.69
FLANGED PIPE PLUS CLOSED ELBOW	0.8
PLAIN PIPE PLUS CLOSE ELBOW	1.60
TUMBLING MILLS (VARIES WITH DESIGN OF MILL)	AV. 2.0

Figure 4-45. Hood Entry Loss In Duct Design

(Courtesy Of American Conference Of Governmental Industrial Hygienists)

The first system involves a procedure for achieving the desired airflow without the use of dampers or blast gates. In this type of design, calculations begin at the branch of greatest resistance and proceed from branch-to-main and section-of-main to section-of-main, on to the filter. At each point of juncture of two air streams, the static pressure necessary to achieve desired flow in one stream must match the static pressure in the joining air stream. This condition exists in any operating system, but if the branches are not in theoretical (calculated) balance, the desired airflows may not be achieved. Static pressures are balanced at the desired flow rates by the choice of suitable pipe sizes, elbow radii, etc.

The second duct system, on the other hand, depends on the use of blast gates (balancing dampers), which are adjusted after installation to achieve the desired airflow in each branch. The calculation procedure for this method also begins at the branch of greatest resistance. Pressure drops are calculated through the branch and through the various sections of the main duct up to the filter. At each section of the main where another branch or submain joins, the desired volume of that added flow is added to the flow in the main. No attempt is made to balance the static pressure in the joining stream. The joining branches are merely sized to give the desired minimum transport velocity at the desired airflow.

After determining the type of system to be used (i.e., blast-gate balance or static-pressure balance), the static-pressure losses through the branch of greatest resistance are calculated for the system. This information provides the basis for choosing the proper fan. (See section 4.2.4.)

The two methods for calculating static pressure in a duct system are: (1) the equivalent-foot method and (2) the velocity-pressure method. If the equivalent-foot method is used, the entry loss of the hood or duct opening is determined using the volume which is required to provide adequate capture velocity, adequate duct-transport velocity, or acceptable volumes of air for general ventilation.

<u>Equivalent-Foot Method</u> (4)

$$h_e = F_h \times VP$$

where:

h_e = entry loss, in. wg

F_h = entry loss factor

VP = velocity pressure in duct $= \left(\frac{V}{4005}\right)^2$

V = air velocity in duct, fpm
= Q/A, where Q = volume exhausted, cfm
A = area of duct, ft.^{2}

The duct area (A), or pipe diameter, may be changed as required so that desired transport velocities are maintained. F_h may be obtained from figure 4-45. After determining VP and F_h, the total length of straight pipe (ft(s)) in the system is determined. Using figure 6-11 of reference 4, the number of equivalent feet of duct (ft(eq)) which corresponds to the elbows, angles, and entries in the system is obtained. Using figures 6-15A and 6-15B of reference 4 to convert feet of ductwork into functional loss, the static-pressure equivalent corresponding to ft(s) + ft(eq) can be found, where:

$$ft(s) + ft(eq) = SP(ft) \qquad (5)$$

The static pressure upstream of the fan is found by the equation:

$$VP + h_e + SP(ft) = \text{total static pressure at inlet of fan} \qquad (6)$$

By calculating the loss for each branch, sizing the ductwork to increase or decrease the resistance, and changing the radii of elbows and the angle of entries, a balanced system can be designed.

Velocity Pressure Method:

The velocity pressure method is an alternate method of duct design. It is based on the fact that all functional and dynamic losses in exhaust ducts and hoods are directly proportional to the velocity pressure. Loss factors for hoods, straight ducts, elbows, branch entries, and other fittings are recognized and are established in terms of velocity pressure. (See figures 6-12 and 6-13 of reference 4.) This concept assures that all duct branches have similar pressure losses.

Either of these approaches provides an adequate method for determining the pressure loss required for proper fan selection.

Additional duct design factors to be considered include:[7]

1. Ductwork must be airtight to prevent escape of contamination in case negative pressure is lost. Gage, number, and size of reinforcements depend on pressure in duct. All seams and transverse joints should be welded, with, insofar as possible, the minimum number of companion-flange gasketed joints necessary for erection and dismantling. Gasketing between all welded joints must be 1/4 in. minimum thickness to provide sealing.

2. Elbows and angles should have a centerline radius of at least two pipe diameters.

3. Use straight-through designs whenever possible.

4. Transitions in mains and submains should be tapered; taper at least five in. long for each one-in. change in diameter.

5. All branches should enter the main at the large end of a transition section and at an angle not to exceed 45^{o}; a 30^{o} angle is preferred.

6. Connect branches only to the top or sides of the main duct with no two branches entering diametrically opposite each other.

7. Provide sufficient support so as to place no load on the connecting equipment, hoods, etc.

8. Provide six-in. minimum clearance between ducts and ceiling, wall, or floors.

9. When blast gates are used for adjustment purposes, they should be placed near the juncture of the branch and main. Dampers should be provided with a means of locking after adjustments have been made.

10 Use round duct whenever possible; in comparison with rectangular duct, it (a) is stronger under negative pressure, (b) provides more uniform airflow, and (c) is easier to join in a leaktight manner. Use rectangular ducts only when the available clearance prevents the use of round ducts.

11. Protect exterior of ductwork by painting if located outdoors.

Following are [illegible]e of the specification requirements applicable to the [illegible] duct[illegible][11]

1. Material - Duct is made of carbon steel, 18 gage minimum (16 gage minimum if field welded).

2. Design Construction - All longitudinal seams and trans[illegible]e joints are welded except that sufficient companion-angle transverse joints are provided for ease of erection and disassembly. All welds are made using procedures and operators qualified in accordance with Government-approved specifications. (See Appendix D.)

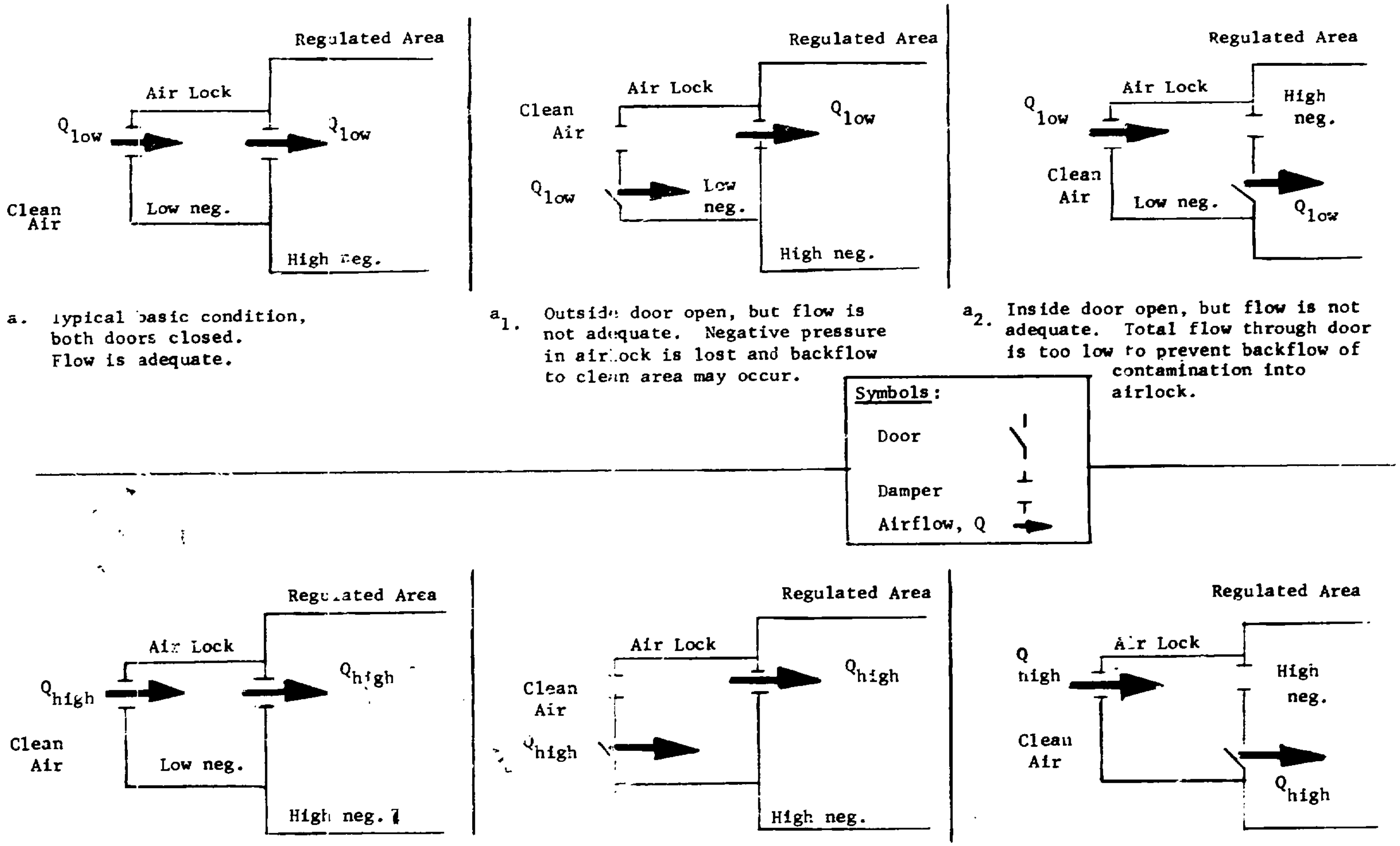
3. Tranverse Joints - Gaskets of mechanical transverse joints are at least 1/4 in. thick, flange wide, of 30-40 Durometer Shore A neoprene material, and meet either ASTM D1056[9] (Grade SCE45) or ASTM D1330.[29] Gasket seating surfaces are smooth (32-64 microinch arithmetic average in accordance with ANSI B46.1[30]) and flat within 1/32 in. per foot total indicator reading (TIR).

4. Painting - Ducts are painted on all exterior surfaces with Rowe Epoloid epoxy paint to prevent corrosion and to simplify decontamination. (See section 4.1.2.8.)

5. Sizing - Gage and reinforcement of ventilation ductwork is sized for a minimum negative pressure of 1.0 in. wg at the filter inlet and a minimum velocity of 1,800 fpm. The duct pressure, for design purposes, should be considered to be no less than the cut-off pressure minus 3.4 in. wg. Since no contaminated particulate matter will be generated by any of the demil processes, an air velocity of 1,800 fpm is considered sufficient to prevent aerosol r vapor from settling out. The ductwork at CAMDS was sized for flows between 1,800 and 2,000 fpm except for two noncritical areas. The airflow was so low in these two areas that extremely small diameter ductwork (three in. ID or less) would be required to achieve the desired velocity. This size was considered undesireable.

4.2.3. Airlock Design

Airlocks are included in the ventilation system to assure that no agent-contaminated air migrates back into nonregulated areas. The volume of air (Q) that should be supplied to an airlock is determined by multiplying the area of the entrance door (A_d) by 100 fpm, i.e., Q in cfm = A_d x 100 fpm. The resulting airflow is sufficient to provide a velocity of 100 fpm when the door to the regulated area is opened. In addition to maintaining airflow into the regulated area, the ventilation-system design must assure airflow into the airlock when the door to the clean area is opened. Refer to figure 4-46 for clarification. Depending upon the location of the airlock, i.e., whether it opens to the outside, alternate designs may be considered.



a. Typical basic condition, both doors closed. Flow is adequate.

a_1. Outside door open, but flow is not adequate. Negative pressure in airlock is lost and backflow to clean area may occur.

a_2. Inside door open, but flow is not adequate. Total flow through door is too low to prevent backflow of contamination into airlock.

b. Recommended basic condition, both doors closed. High flow insures at least 100 fpm when door is opened.

b_1. Outside door open and outside damper closed. No backflow into clean area.

b_2. Inside door open and inside damper closed. No backflow of contamination into airlock.

Figure 4-46. Recommended Methods To Prevent Backflow In Airlocks

An alternate method involves supplying tempered air to the airlock in accordance with above equation $Q = A_d \times 100$ fpm to assure inward flow into the regulated area. For this purpose, a properly designed and sized damper must be provided between the airlock and the contaminated area. Proper sizing is required to allow the calculated volume of air to enter the regulated area and maintain the desired static pressure. (The airlock itself is under negative pressure.) The damper may be pneumatically or hydraulically controlled so that when the door to the regulated area is closed, air passes through the damper and the desired differential pressure is thus maintained.

When the access door to the regulated area is opened, the damper closes automatically and all air is drawn through the opened door. To ensure there is no migration to the outside, the supply duct must be dampered. This damper is pneumatically or hydraulically controlled so that when the outside door is opened, the supply damper closes. This should allow sufficient air volume to maintain an inward velocity of approximately 100 fpm through the outside door.

Another method is to place the damper in an outside wall, i.e., between the airlock and ambient air. A damper must also be placed in the wall between the airlock and the regulated area. Air for comfort ventilation must also be supplied. In most instances this is a small portion of the air supplied to the airlock. In this configuration the outside damper inlet has no air-tempering capability, which could be of importance if this damper opens directly to the outside and extreme temperatures are encountered. The dampers are operated either penumatically or hydraulically and controlled by switches on the doors.

The air inlet does not require dampering unless flow through it is large compared to the total flow required. When the outside door is opened, the damper to the regulated area should open and then return to the normal position when the door is closed. Upon opening the door to the regulated area, the damper on the outside wall should open and then return to the normal operating position when the door is closed.

Either of the methods described above may be used to provide sufficient flow and the required negative pressures in the airlock. Although other designs may be used, care must be taken to ensure that the velocity of air into the regulated area is approximately 100 fpm. Although this value is less than the prescribed 150-fpm inward velocity recommended for openings into regulated area, a lower value is allowable for personnel doors because the liklihood of crossdrafts affecting inward velocity is decreased in the airlock. In addition, the total area of a door opening is seldom experienced since personnel open the door only wide enough to enter, thereby resulting in an inward velocity greater than 100 fpm. Observations and tests performed on portions of the CAMDS system have indicated that use of the 100-fpm velocity design criteria results in an adequate airflow to prevent agent migration.

Some airlock designs may require mechanically assisted opening devices because of the differential pressures, but these are not required at CAMDS. An emergency exit from the regulated area should be provided to ensure that personnel cannot be trapped inside should the opening mechanisms fail on the airlock doors. Emergency exits do not require airlocks but provisions to prevent unauthorized entry should be made.

4.2.4. Fan Selection

Fan speed is directly proportional to the volume of airflow in the system. The total pressure and static pressure in the system vary as the square of the fan speed. Fan power requirements are proportional to the cube of the fan speed.

Fan size is specified by volumetric flow rate and fan static pressure. The volumetric flow rate is calculated by totaling the individual airflows necessary to operate the local exhaust hoods, balance the ductwork, and provide general exhaust ventilation. Fan static pressure (SP_{fan}) is calculated by the general equation,

$$SP_{fan} = SP_{outlet} - SP_{inlet} - VP_{inlet} \tag{6}$$

where:

SP_{outlet} = static pressure in in. wg measured at fan outlet. It is always positive and can be calculated by totaling losses due to friction in exhaust stack and turbulence in elbows.

SP_{inlet} = static pressure in in. wg measured at fan inlet. It is always negative and can be calculated by totaling losses due to negative pressure in regulated areas, acceleration of air into hoods, turbulence in hoods, elbows, branches, and entries, and friction in ductwork and filters.

VP_{inlet} = velocity pressure in in. wg measured at fan inlet. It is always positive and can be calculated using a variation of equation (3) in section 4.2.2.

$$= \left(\frac{V_{inlet}}{4005}\right)^2 \tag{7}$$

where:

V_{inlet} = duct velocity at fan inlet, in fpm.

The actual selection of fan size and speed is usually made from a fan rating table published by the fan manufacturer. It shows the performance of a particular fan over the entire range of pressures and speeds at which the fan is capable of operating. Straight line interpolation can be used if the desired volume and pressures are not listed in the table. Fan tables are based on the manufacturer's test data, which is collected under standard conditions. Standard air has a density of 0.075 lb/ft^3; when air density varies significantly from this value corrections have to be made. For design purposes, corrections should be made if the facility will be located where the altitude is more than 1,000 ft above sea level, or if the temperature of air handled will normally be less than 40°F or greater than 100°F.[12]

The volume of air handled by a fan at a given rotational speed remains relatively constant; however, as the density changes the mass flow rate changes, causing the static pressure and power requirements also to change. Correction can be made by multiplying the calculated fan static pressure by a density correction factor before entering the fan rating table. Density correction factors may be obtained from reference 4 or calculated using the equation,

$$\text{Density factor} = \frac{d_{actual}}{d_{standard}} \tag{8}$$

where:

d = density of air

The fan should be located outside the contaminated area and as close to the discharge stack as possible. The air cleaning system is on the suction side of the fan and also outside the work area. Exhaust stack discharge must not be located near air intakes (see section 4.1.2.13).

4.2.5. Dampers[7]

Dampers are the valves of the air cleaning and ventilation system. By definition[16], a damper is any device that controls pressure, direction, or volume of airflow in a ventilation system, including those items normally classed as valves when used in piping systems. Clear, concise specifications must be established for mechanical strength, for leakage rate at maximum operating conditions, and for the ability to perform under required operational and emergency conditions.

Operability of linkages must be assured through specification of and requirement for cycling at minimum torque requirements under full load. Static testing of closed dampers should be required to verify strength and leaktightness for use in critical applications. All features important to proper operation should be stipulated in detail, including materials of construction, permissible lubricants, bearings, blade design and edgings (if permitted), blade locking mechanisms, supports, operator type and capability, and accessibility of operator, linkages, blades, and bearings for maintenance.

Other factors to be considered in the design of dampers for demil applications include function of damper; type of construction; dimensions and space limitations; pressure drop across closed damper; normal blade operating position; method of mounting damper; blade orientation relative to damper case; operator type and power source; seismic requirements; requirements for position indicator, limit switches, and other appurtenances; configuration of damper; permissible leakage through closed damper; space required for service; airstream temperature range; orientation of damper in duct; direction of airflow; failure mode and blade position; maximum closing and opening times; and method of shaft sealing. (See section 5.3 of reference 7.)

In conventional ventilation applications, procurement of dampers is generally accomplished by specifying little more than a manufacturer's make and model number "or approved equal." This practice, however, is inadequate for chemical and other potentially high-risk applications. Therefore, a method of damper specification based on classification of important features has been developed and is included in reference 7. The classification enables the designer to make a rational selection of dampers, independent of manufacturer's make and model number, for a specific application. Although the classification was written for use in nuclear applications, it is nevertheless the best summation of damper information currently available. In fact, it served as the basis for the CAMDS ventilation specification,[11] to which the damper designer is also referred.

See also section 5.3 regarding dampers.

4.2.6. Automatic Controls[7]

Automatic control of the ventilation system is desirable, if not mandatory, when rapid response is required to variations in system control parameters, malfunctions, or operational upsets. To maintain the differential pressures necessary for directional control of airflow, many ventilation systems require continuous fan operation and immediate switching to an alternate fan (or filter housing as in the case of CAMDS) in the event of an emergency or failure of the fan or its power supply.

Automatic control is also desirable because of the shortcomings of human nature. Despite the best procedures and administrative controls, operational personnel will, in many cases, be primarily concerned with performance of day-to-day duties relating to the function of the facility with little more than minimal attention to proper operation of the ventilation system. In any emergency, the first reaction of many may be to leave rather than stay in a potentially dangerous area to make the adjustments necessary for a manually controlled system.

On the other hand, automatic control is expensive and, in some applications (nuclear), has demonstrated serious shortcomings in reliability. Features considered essential to the reliability of an automatic control system for chemical demil operations include (1) design by competent instrument engineers; (2) use of components of known reliability; (3) availability of skilled and competent technicians for servicing instruments; and (4) careful evaluation of modifications to the ventilation system with respect to their effect on the automatic control system, and vice versa.

The usual control procedure for an exhaust system is to maintain constant airflow and monitor pressure, as well as airflow, to ensure safe operation. Control limits for safe operation are determined in the design stage, and the system is operated within these limits. Any modification of the ventilation system requires a reevaluation of the control limits and, for automatic control systems, an evaluation of the change on the control system. In considering the consequences of certain system failures or catastrophes (such as fire, earthquake, tornado, or flooding), factors to be taken into account should include (1) control system design, (2) instrumentation selection and location, and (3) actuating-line location and installation. The types of failures to be prepared for should include such things as (1) single-component failure, (2) single-system failure, (3) ventilation system deterioration or failure, and (4) power failure (electrical, pneumatic, etc.).

At CAMDS, the chief example of automatic control is the pneumatically operated damper through which air enters a potentially contaminated area. These dampers are designed to close if the ΔP between the contaminated area and the area surrounding it drops below a preset level of 0.05 in. wg; also, as a safety feature, these dampers fail-close if the compressed air supply or electrical power is lost. Although the normal ΔP is at least 0.1 in. wg, the value of 0.05 in. wg was selected to allow for pressure fluctuations due to door openings and still provide sufficient negative pressure to preclude the outward flow of contaminated air.

A Photohelic gage with a single set-point is used to send a signal when a low static-pressure condition exists. The only differences between this gage and those used to control the airflow are: (1) the dials on the latter gages are calibrated with two set-points representing the lower and upper airflow limits, and (2) the scale is in cfm instead of in. wg.

The status of the filters and the positions of the isolation dampers at CAMDS are monitored on the control room console shown in figure 4-47.

4.2.7. Makeup Air

Makeup air is required to replace the large volumes of air exhausted by hoods and the general building exhaust system. The supply of makeup air must permit the control of building pressure and of airflow from space to space. The operation of local exhaust hoods contributes to general building exhaust for heat control. After the amount of airflow needed to remove heat has been determined, it should be compared to the amount of air being exhausted by the hoods, with the larger of the two being the amount of makeup air that must be added.

Air-supply inlets should be located away from local exhaust hoods and general exhaust outlets. Crossdrafts caused by supply inlets can interfere with contaminant control at local exhaust hoods. The effectiveness of general room ventilation for heat control will be reduced if airflow is short circuited by placing inlets and outlets close together. In regulated areas air has to be supplied through dampers that maintain desired negative pressure in the regulated area over a range of flows from near zero to the flow selected.

4.2.8. Heat Control

In case of excessive heat and/or humidity, exhaust ventilation may be used if a source of cooler air is available. In order to arrive at the air volumes required, it is necessary to estimate the summation of all sources of both sensible and latent heat, as well as to determine in advance the temperature rise or humidity rise which will be acceptable. The volume of air (Q) required for sensible heat control may be estimated from the equation:[4]

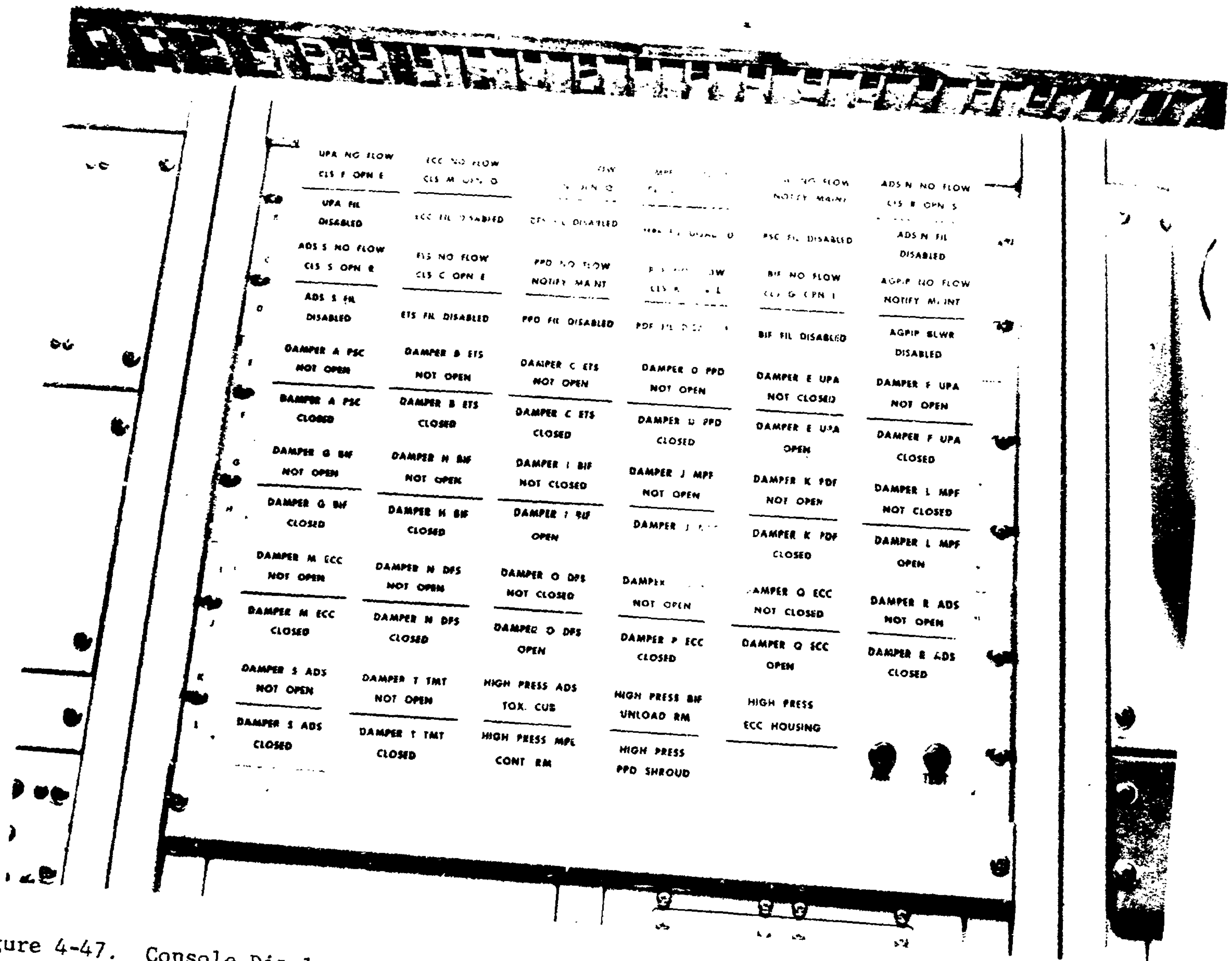


Figure 4-47. Console Display In CAMDS Control Room Of Filter And Isolation Damper Information

$$Q \text{ in cfm} = \frac{\text{Total BTU/hr.}}{1.08 \times \text{Temp. rise } (^{o}F)} \tag{9}$$

The total BTU's per hour represents the sensible heat released in terms of sun load, lights, and motors. Personnel heat load and hot processes are part sensible and part latent, and it is necessary to estimate the amounts or percentages of each. In the majority of cases the sensible heat load far exceeds the latent heat load so that the design can be calculated only on the basis of sensible heat.[4] If latent heat loads are high, calculations should also be made to determine which heat source requires the higher quantity of air.

In certain hot-process applications, such as furnaces, it is unnecessary and impractical to attempt to control the heat from the process by ventilation. If the operation is such that remote control is possible, an air-conditioned booth or cab may be necessary to keep the operators reasonably comfortable in an otherwise intolerable atmosphere.*

In most cases, outside air is supplied in the winter months at or slightly above desired work-area temperatures, and during the summer at whatever outdoor temperature is available. The distribution of the air within an enclosure is vitally important in order to maintain satisfactory environmental conditions for the personnel in the work area. The hourly and yearly costs for the air thus provided may be calculated as follows:

$$\text{Hourly cost} = \frac{0.001 \times QN}{q} \times C \tag{10}$$

$$\text{Yearly cost} = \frac{0.154 \times D \times dg}{q} \times C \tag{11}$$

where:

Q = air volume, cfm
N = required heat, BTU/hr/1,000 cfm (figure 4-48 and table IV-11)
D = operating time, hours/week
q = available heat per unit of fuel (table IV-12)
dg = annual degree days (table IV-13)
C = cost of fuel, $/unit

*See "TLVs Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977" (reference 45) for guidance in determining heat stress requirements.

Figure 4-48. Average Winter Temperatures, December To February, Inclusively. (Courtesy U. S. Weather Bureau)(Extracted From Reference 4)

Table IV-11. Required Heat Versus Average Outside Air Temperature (Courtesy Of American Conference Of Governmental Industrial Hygienists)

Average Outside Air Temperature (°F)	N, Required Heat (BTU/hr/1000 cfm at 70°F)
0	75,500
5	70,000
10	65,000
15	59,500
20	54,000
25	48,500
30	43,000
35	38,000
40	32,500
45	27,000
50	21,500
55	16,000
60	11,000
65	5,500

Table IV-12. Available Heat Per Unit Of Fuel (Courtesy Of American Conference Of Governmental Industrial Hygienists)

Fuel	BTU Per Unit	Efficiency (%)	Available BTU Per Unit q
Coal	12,000/lb.	50	6,000
Oil	142,000/gal	75	106,500
Gas:			
(a) Heat Exchanger	$1{,}000/ft^3$	80	800
(b) Direct Fired	$1{,}000/ft^3$	90	900

Table IV-13. Annual Degree Days
(Courtesy Of American Conference Of
Governmental Industrial Hygienists)

Air Discharge Temperature F (Base)	Albany	Boston	Chicago	Cleveland	Detroit	Minneapolis	N. Y.	Phila.	Pittsburgh	St. Louis	Wash., D. C.
				Annual Heating Degree-Day Normals							
80	11782	10409	10613	11343	10959	13176	9284	9652	10797	8943	8422
79	11425	10049	10277	10982	10605	12826	8937	9300	10436	8624	8089
78	11052	9690	9940	10621	10256	12478	8596	8954	10076	8310	7764
77	10709	9342	9610	10265	9914	12135	8265	8619	9723	8003	7446
76	10356	8994	9283	9915	9581	11797	7938	8285	9379	7702	7139
75	10009	8652	8972	9570	9247	11475	7620	7959	9036	7413	6835
74	9669	8317	8656	9229	8920	11142	7308	7641	8702	7121	6538
73	9335	7990	8349	8898	8599	10816	7004	7328	8373	6839	6250
72	9007	7668	8046	8567	8291	10496	6706	7028	8050	6560	5974
71	8682	7354	7750	8248	7981	10180	6421	6728	7740	6289	5703
70	8364	7046	7468	7928	7678	9870	6146	6438	7429	6023	5438
69	8056	6749	7163	7617	7383	9567	5871	6158	7127	5767	5179
68	7750	6458	6905	7313	7100	9269	5606	5886	6833	5523	4929
67	7452	6175	6635	7016	6816	8975	5349	5613	6546	5277	4690
66	7162	5903	6373	6722	6543	8687	5101	5360	6272	5053	4455
65	6881	5633	6122	6445	6278	8410	4858	5109	5997	4822	4229
64	6607	5370	5875	6165	6020	8131	4621	4864	5734	4595	4014
63	6340	5118	5638	5897	5772	7858	4394	4628	5483	4379	3798
62	6081	4873	5399	5636	5533	7590	4176	4397	5234	4168	3588
61	5829	4634	5164	5381	5290	7339	3957	4172	5006	3963	3383
60	5586	4399	4936	5140	5054	7086	3747	3952	4769	3761	3182

4.2.9. Redundancy and Safety Features

The CAMDS ventilation system provides multiple small filter units. For a minimal additional expense, extra sections of ductwork were incorporated into the design to join adjacent filter units to provide parallel redundancy. An isolation damper was installed in each branch to control the airflow. The exterior ductwork and locations of isolation dampers at CAMDS are shown schematically in figure 4-49. Figures 4-50 and 4-51 show sections of ductwork containing these isolation dampers.

The isolation dampers at CAMDS are high-quality, manually-operated (by pull chain) butterfly valves. A set of limit switches is attached to each damper to provide a signal to the control room indicating the position of the damper (either full-open or full-closed). Under normal conditions, the isolation damper between the ventilated area and the filter unit is full-open while all other adjacent isolation dampers are full-closed. Since these dampers are leaktight, each filter ventilates only its designated area with no effect on the ventilated area of any other filter unit.

If a filter fails, however, operating personnel can open and close various dampers to enable a second filter unit to pull some or all of the needed airflow from the ventilated area designed to be serviced by the failed filter unit.

For CAMDS it was decided that manual dampers are more reliable than automatically-operated pneumatic dampers. If the compressed-air supply is lost, the latter type dampers cannot function. Instantaneous switchover is not essential. In a well-designed leaktight area such as the PPD shroud, the inlet dampers to the contaminated area close when airflow is lost. These inlet dampers fail in the closed position due to loss of power or compressed air and close if ΔP between the contaminated and outside areas drops below a preset value (see section 4.2.6.). Since these dampers close quickly and are essentially leaktight, some negative pressure is retained in the affected contaminated area(s) for several minutes.

As stated in section 3.4, the filter system design should incorporate both series and parallel redundancy. Since total redundancy (i.e., both series and parallel) is extremely expensive, the degree of redundancy provided usually becomes a tradeoff between cost and risk. The development of alarm and emergency procedures and a thorough training in these procedures are essential.

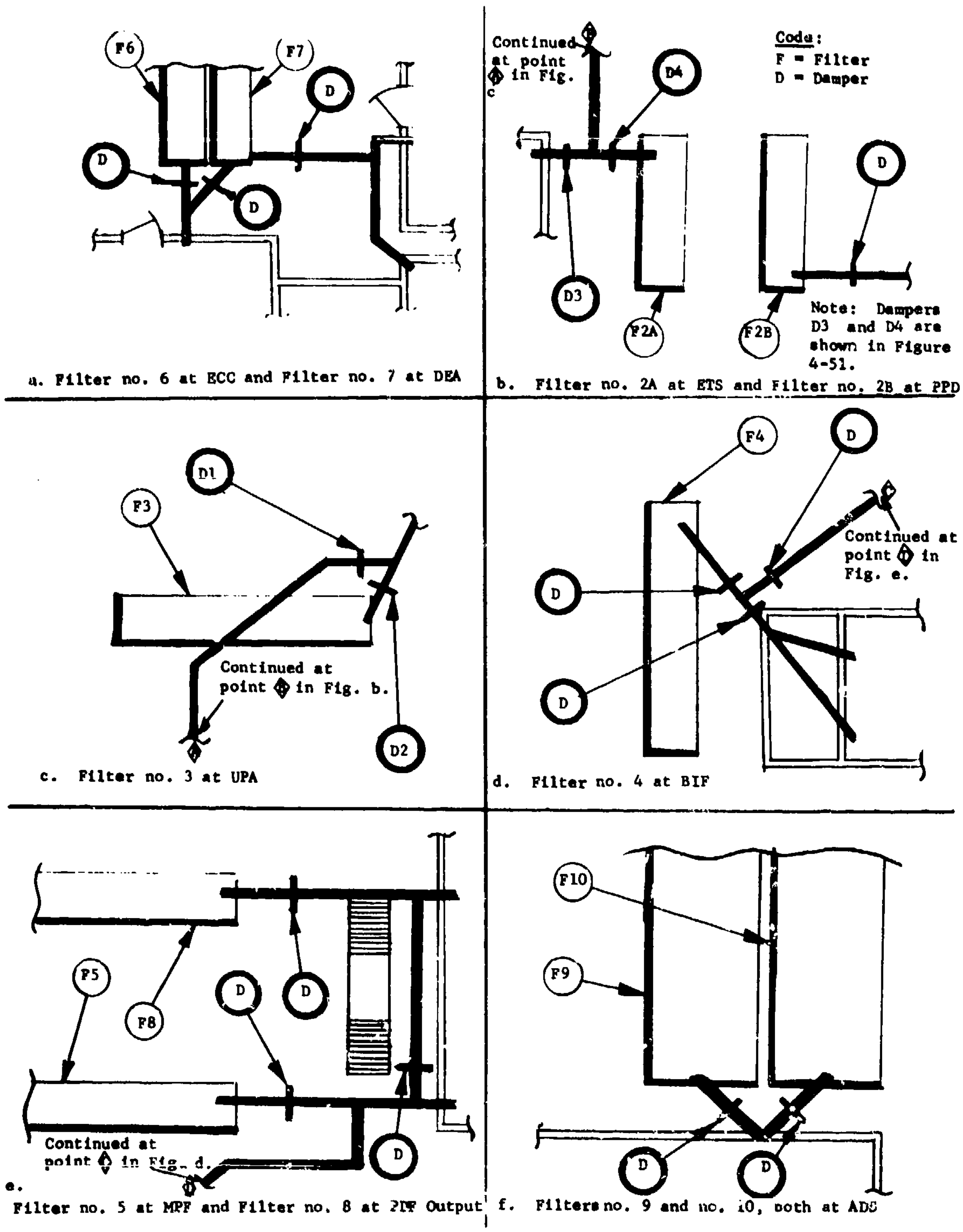


Figure 4-49. Location of Redundant Ductwork Containing Isolation Dampers At CAMDS

(Note: Refer To Figure 4-15 For CAMDS Layout Showing Location Of Filter Systems)

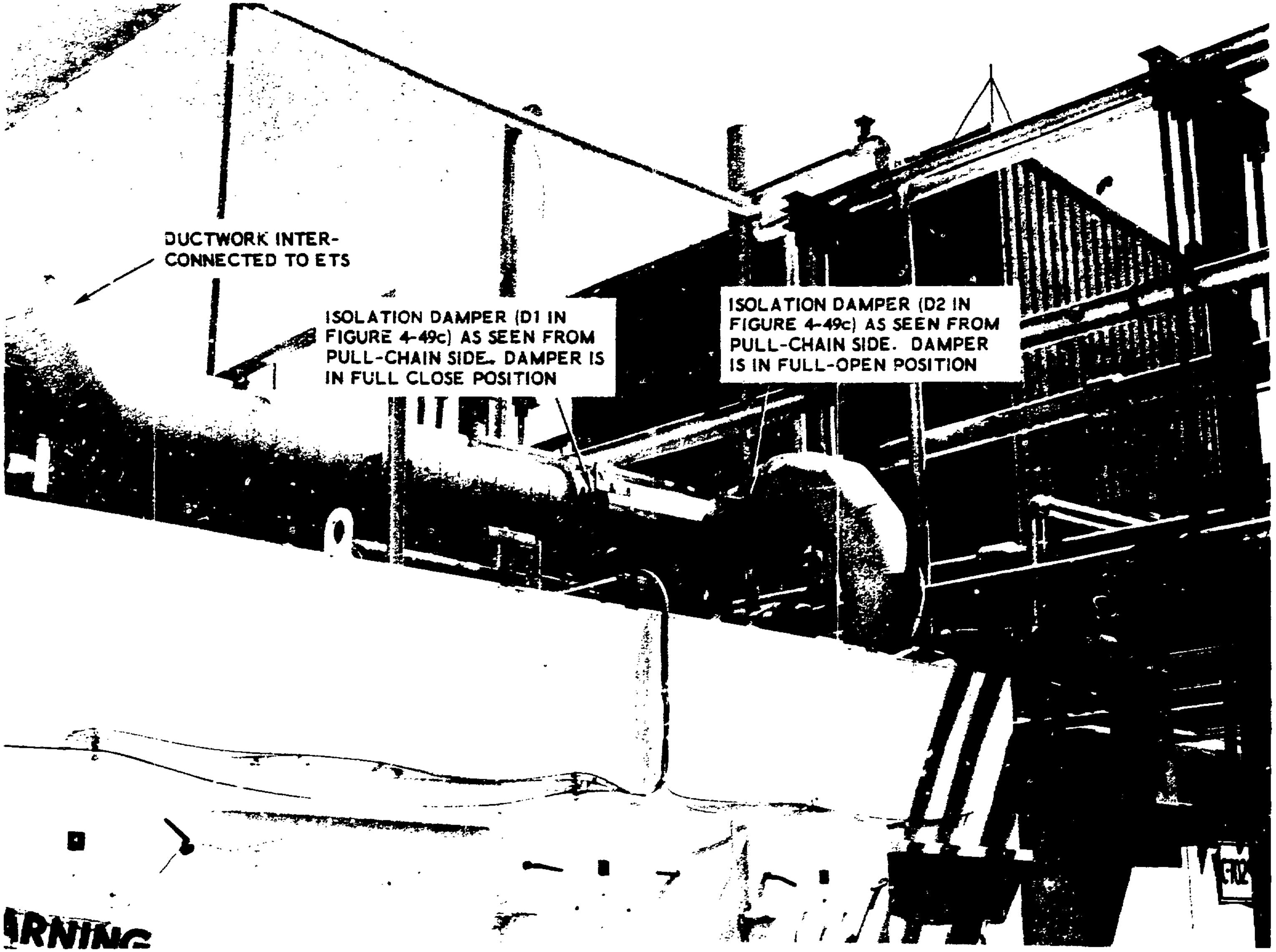


Figure 4-50 Type II Filter System (3,000 Cfm) For Unpack Area At CAMDS Showing Isolation Dampers And Interconnecting Ductwork. This Is Only Filter System On Which Live-Agent Challenge Test Has Been Conducted To Date.

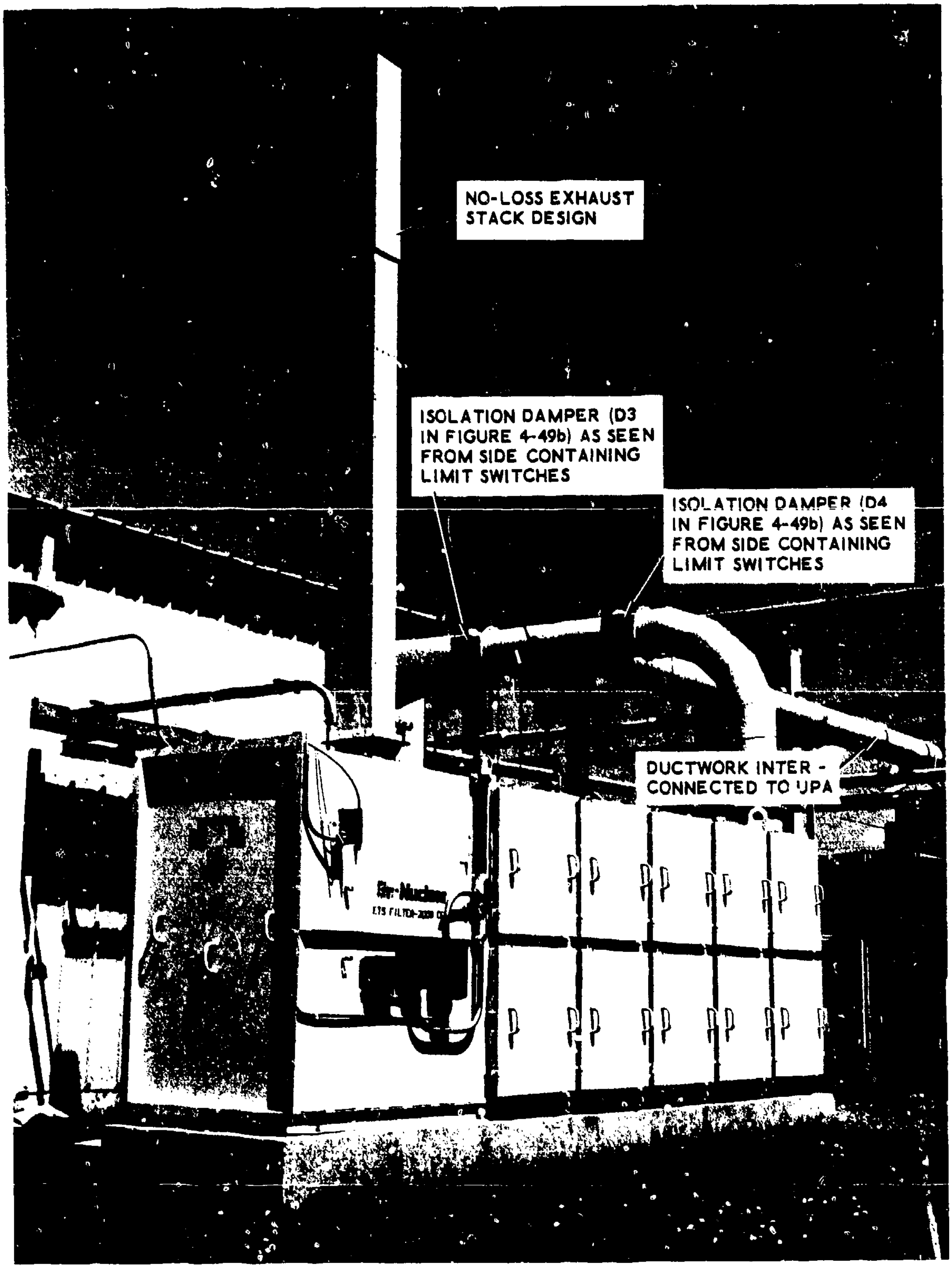


Figure 4-51. Type I Filter System (2,000 Cfm) For Explosive Treatment System At CAMDS Showing Isolation Dampers And Interconnecting Ductwork

The CAMDS filter systems were not designed to meet fully either series or parallel redundancy requirements. Although these filter systems do contain two adsorber banks in series with agent monitors in between, true series redundancy is not realized because neither one of the adsorber banks is guaranteed to provide more than a 10^4 reduction in concentration, whereas a 10^8 reduction is needed to meet the emission standards under the initially estimated worst-case challenge condition (see section 4.1.1.3.2).

Even though a 10^4 reduction is the maximum that can now be guaranteed for each bank, the actual reduction capability is probably significantly better. The 10^4 reduction figure is based on the sensitivity of the freon leak test of the adsorber cell; if the state of the art for portable freon measuring equipment were to improve, it is conceivable that an order of magnitude of one to two times higher could be measured.

All but two of the 12 CAMDS filter systems are connected in parallel with another system. The two systems not connected in parallel ventilate the PSC change area and medical module where the amount of contamination present, if any, is minimal. Even though the other filter systems are parallel with at least one other filter system, none meet the basic criteria of a complete parallel system as defined in section 3.4.

Each of the CAMDS filter systems exhausts a specific area. In a true parallel redundant system, if the primary filter fails, the backup (parallel unit) starts up. At CAMDS, the specific action taken depends on the conditions at the time of the incident. For example, if filter A fails, filter B by adjusting certain dampers may be made to pull exclusively from the area that filter A was pulling. However, it is likely that when filter A fails, some contamination may be present in the area served by filter B. It may be decided then to adjust the damper to enable filter B to pull partially from both areas A and B. There is one area at CAMDS where three filter units are interconnected,* so that if one fails several possible adjustments can be made, depending on the type and quantity of toxic materials in each area.

The function of the CAMDS parallel system is not to switch filters and continue operations as in a truly parallel system, but to maintain sufficient negative pressure in all areas to assure no outward leakage of contamination while an orderly shutdown, including decontamination if necessary, takes place. Once shutdown is complete, the defective filter system is serviced. Normal operations resume only when all filter systems are fully operational.

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*Filters no. 4, 5, and 8 in figure 4-15.

The function of the CAMDS parallel system is not to switch filters and continue operations as in a truly parallel system, but to maintain sufficient negative pressure in all areas to assure no outward leakage of contamination while an orderly shutdown, including decontamination if necessary, takes place. Once shutdown is complete the defective filter system is serviced, and normal operations resume only when all filter systems are fully operational.

5. OPERATIONAL CONSIDERATIONS

5.1. Controls and Instrumentation

5.1.1. Controls[7]

Monitoring and control of all but the most simple filtering/ventilation facilities are desirable in both automatically controlled and manually controlled systems. Most changes that take place in a high-efficiency air cleaning system usually occur very slowly and can be monitored by a routine check of negative pressure, differential pressure and airflow by operating personnel who are primarily responsible for other functions in the plant. Abnormal conditions are best signaled by an alarm which triggers when a monitored parameter rises above or falls below some predetermined set point. A centralized control system is preferable for this operation in that it has the advantage that such readings can be made, the effect of changes to the monitored parameters can be determined, and corrective action can be taken without a trip to the field. However, sufficient local instruments at the point of interest should also be provided to facilitate maintenance and inspection and to provide a check on the central instrumentation.

Centralized control, particularly if instruments and control switches (e.g., for fans and dampers) are laid out on a graphic display panel, enables the operator (1) to rapidly assess a situation, (2) to determine the cause of an upset condition, (3) to determine its interaction with other systems and its safety ramifications, and (4) to take rapid action when necessary. (See figure 4-47.) The system response to corrective action can be monitored, reassessed and modified in minimum time without requiring personnel to enter potentially contaminated areas. Centralization of control also provides a focal point where operational information can be processed under normal operating conditions for feedback purposes, and where knowledgeable personnel can be contacted in an emergency.

5.1.2. Instrumentation[7]

Safe and reliable operation of a filtration/ventilation system, whether automatically or manually controlled, requires instruments to monitor critical operating parameters. At a minimum, such instrumentation should measure pressure drop across each individual bank of filters (not just a single instrument to read pressure drop across the total filtration system) and total airflow exhausted through the filter system. Pressures in critical operating areas of the facility and differential pressures between areas of different potential contaminations may also have to be monitored.

The principal requisite for locating instruments is accessibility. An instrument that is out of easy reach or is not easily readable will not be maintained or used. Instruments should be located at eye level or only slightly above or below. Panel mounts should be provided for fragile items and those requiring service entry from the rear.

Instruments that are adversely affected by vibration, particularly those with delicate electrical contacts or springs, should be installed on vibration isolators or on panels that are mounted on vibration isolators. Where stable support is not available, the panel should be mounted nearby or remotely on its own standard. (See figure 4-4.) Instruments with related functions should be grouped on a single panel or adjacent to one another so that operators can correlate related readings, such as pressure drop across filters and airflow in the ducts, without going to several locations. (See figure 4-28.)

Critical ventilation systems that cannot be permitted to fail or to be misunderstood (because of erroneous instrument readings) may be fitted with redundant instrumentation for certain critical parameters. Redundant instruments must be totally independent so that failure of one, from a cause either internal or external to the instrument/ventilation system, cannot affect the other.

Installation of instruments out-of-doors should be avoided when possible but not at the expense of decreased sensitivity, reliability or inaccessibility. When located outside, instruments must be protected from the weather. Indicating fluids in manometers must be of a type that do not freeze or boil at the temperatures occurring at the site. Plastic instruments, instrument cases, and instrument cover glasses should not be used in outdoor installations because of crazing and/or discoloration of the plastic. (See section 4.1.2.12.5.) Raintight electrical cabinets, NEMA class 3, are recommended; NEMA class 4 (water-tight) or class 12 also provide acceptable protection if NEMA class 3 is not available.

In low-hazard areas where easy access is possible, the requirement for pressure drop and airflow readings for simple, noncritical systems can often be met by providing for temporary attachment of portable instruments. For pressure drop readings, a length of tubing can be attached to the pressure taps or inserted through holes in the sampling ports. A hand-held pitot tube may also be inserted, if desired, through a suitable sampling port in the duct. For critical systems, however, permanently installed instruments must be provided in accessible locations as close to the monitoring point as practicable.

Actuating fluid (e.g., instrument air) and sensing lines should be large enough so that they cannot become plugged due to freezing of condensed water which may collect in them, or from contaminants that inadvertently get into the lines. Sensing lines should be kept as short as possible to minimize the time response to parameter changes, and they should have a minimum number of bends and no flow restrictions. Sensing lines should be rigid to prevent expansion under pressure or temperature extremes that could result in false readings or multiple short-term parameter variations. Preferably, lines should be run and instruments located above the ducts to minimize condensation problems. Because such locations are often impossible, as a minimum, lines should be sloped to low points fitted with drip legs and the instruments themselves also fitted with drip legs.

Sensing lines located in or serving contaminated spaces or spaces containing corrosive fumes should be made of stainless steel. Instruments should be isolated from contaminated spaces so that migration of such contaminants to the instrument is minimized. In particularly critical applications, a very-low-velocity purge line may be attached to the actuating fluid or sensing line; the purge flow must be very low, of course, to avoid influencing operation of the device or affecting its readings.

See sections 4.1.2.5, 4.1.2.6, and 4.1.2.12 for a discussion of instrumentation as applicable to CAMDS.

5.2. Agent Monitoring Equipment

5.2.1. General

Agent monitors perform two primary functions: (1) provide immediate warning of hazardous situations, and (2) measure low-level concentrations of agent (stack emissions and working area standards) to guard against cumulative effects over an extended period of time. To meet these requirements, relative to GB and VX, a system of dual detectors is used in each filter system. An automatic agent monitor/detector with fast response time warns of hazardous situations, while a bubbler absorption system collects samples which are analyzed in a laboratory for low-level agent concentrations. The sensitivities and response times of the two monitoring systems currently in use for this purpose - M8 detector alarm and bubblers - are shown in Table V-1. These devices may be housed, as at CAMDS, in a shelter immediately adjacent to each filter housing (see figure 5-1).

Although a suitable fast-response monitor - similar to the M8 detector - is not now available for use with the mustard agents, such a device is being developed. In addition, more sophisticated equipment offering greater sensitivity and/or faster response times with GB and VX are presently being evaluated.

Brief descriptions of the M8 detector and bubbler absorption system follow.

Table V-1. Sensitivity and Response Time Of Available Agent Detectors For Use In Filter Systems

GB Detectors	Sensitivity (mg/m^3)	Response Time[(a)]
M8 Alarm	0.2	1 min
Bubblers	0.0001	2 hrs
Bubblers	0.000003	13 hrs
VX Detectors		
M8 Alarm	0.4	3 min
Bubblers	0.00001	2 hrs
Bubblers	0.0000003	13 hrs
Mustard Detectors		
Bubblers	0.003	2 hrs

(a) Response times for bubblers include one hour for analysis and remaining time for sampling.

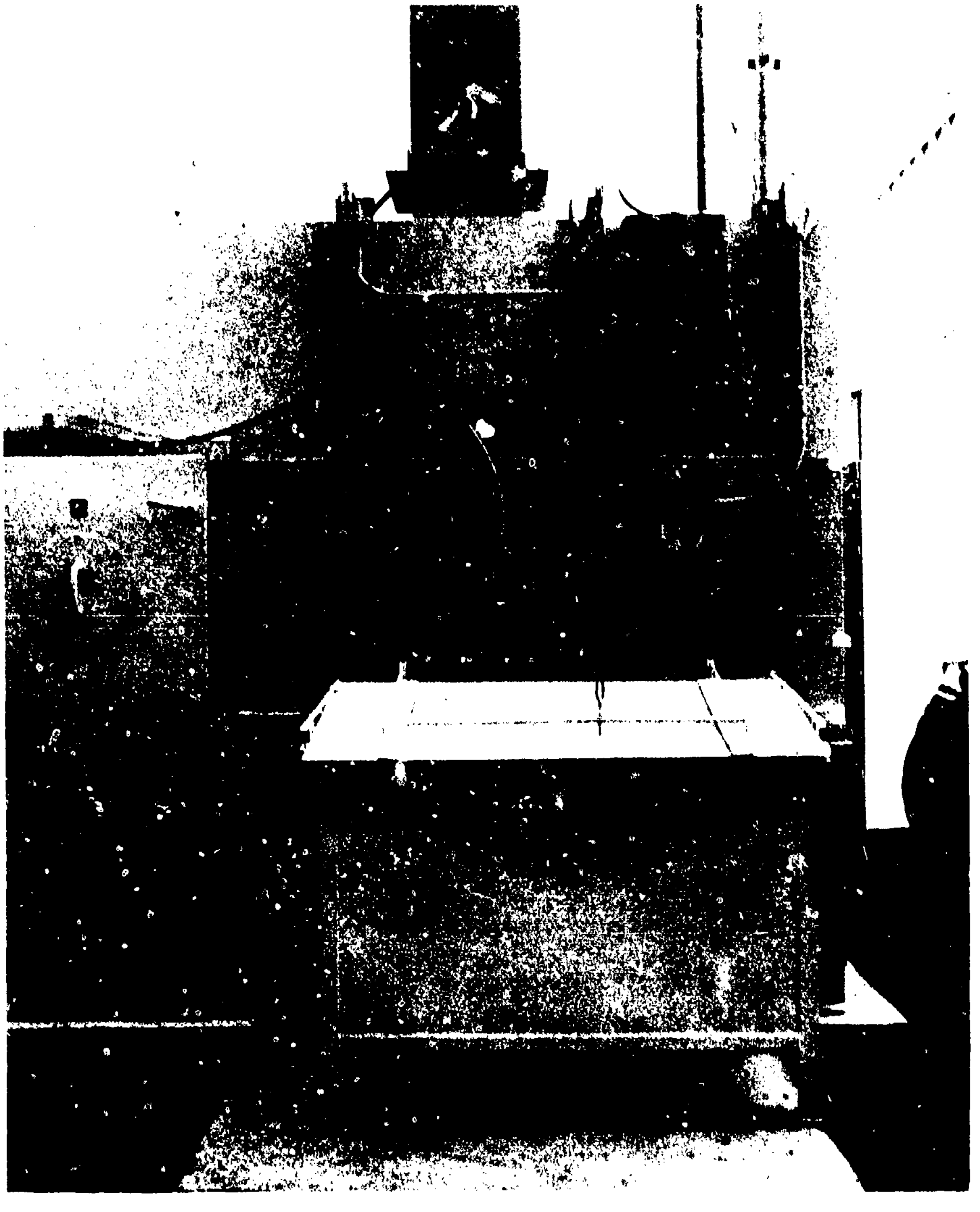

Figure 5-1. Environmental Monitoring Shelter At CAMDS Used To House M8 Detector/Alarm And Bubblers

5.2.2. M8 Detector/Alarm

The M8 detector/alarm* is used to continuously monitor the area between the two adsorber banks of each filter system for GB and VX. Although located outside the filter housing, the alarm is connected to the housing interior by means of a remote sampling probe. When the contamination level exceeds the sensitivity threshold of the detector, it emits an audible/visual alarm in the control room to warn of a breakthrough of the first adsorber bank. At CAMDS, as soon as the alarm occurs the sampling lines are manually removed from the sampling port between the adsorber banks and reinstalled in the exhaust stack, where the filtered air exiting the stack is sampled until the first adsorber bank is replaced. At this time, the sampling line is returned to its original monitoring location between the adsorber banks.

Operation of the M8 detector/alarm on a continuous basis requires that certain operational checks be performed during every shift (or at least every 12 hours). This procedure is described in detail in TM-3-6665-225-12.[31]

5.2.3. Bubblers

Bubblers are used in conjunction with the M8 alarm to collect air samples downstream of the first stage of adsorbers and simultaneously in the emission stacks. Toxic gases, if any, in the airstream are collected in the bubbler solution and chemically analyzed. During monitoring, the bubblers are maintained at $1.5 \pm 0.5^{\circ}C$ to prevent vaporization of the dissolved gases. Bubblers are changed hourly and, after sampling, are transported to the laboratory for analysis. Handling and transportation must be done carefully to avoid breakage and loss of the contents. Under certain conditions (e.g., when monitoring the emission stack after breakthrough of the first adsorber stage), it may be necessary to change the bubbler at more frequent intervals - such as every thirty minutes - in order to monitor contamination levels more closely.

Procedures for handling and agent-challenging of bubblers are given in reference 13.

*This is actually the M10 alarm, which is the plant version of the M8 alarm, but is more commonly referred to by the latter name.

5.3. Dampers[7]

Damper operators should be factory-mounted by the damper manufacturer and installed outside the airstream. The manufacturer should also establish the torque requirements for the dampers based on operating conditions specified by the user. The damper operator should be capable of (1) producing a minimum of 1.5 times the torque required to move the blades from full-open to full-closed position, and (2) enabling the damper to meet the specified leaktightness in the closed position under the maximum service.

After installation of the dampers, an acceptance test must be conducted. The following procedure, used at CAMDS, is recommended:

> Cycle each damper at least 25 times through its full range of motion to verify the free operation of all parts and the correct adjustment, positioning, and seating of the blades. Upon completion of the 25 cycles, adjust the damper as necessary. Balance and test the ventilating system in accordance with reference 11.

Refer to section 4.2.5 for design information regarding dampers.

5.4. Emergency Considerations

5.4.1. General[7]

The ventilation and air filtering systems of a process in which toxic chemical agents are handled are integral parts of the containment of the facility. In the event of an operational upset, power outage, accident, fire, or other emergency, it is essential that these systems remain operational until all contamination within operating areas has been reduced to a safe level, at which time shut-down may occur.

Some damage to or degradation of the ventilation system may not be completely avoidable in the event of a serious incident. Consideration must be given to (1) the possible effects of emergency conditions on the ventilation and air cleaning systems including damage to the filters and adsorbers from shock, overpressure, heat, and fire; (2) the design and arrangement of ducts and air cleaning components to alleviate these conditions; (3) means of switching to a redundant air cleaning unit, fan, or alternate power supply; and (4) methods of controlling the exhaust system during failure conditions.

To provide the necessary protection to the public and to plant personnel, air cleaning and ventilation system components on which containment leakage-control depends must remain essentially intact and serviceable under the upset conditions. These components must be capable of withstanding the differential pressures, heat, moisture, and stress of the most serious type of accident predicted for the facility, with minimum damage and loss of integrity, and they must remain operable long enough to satisfy system objectives.

See also section 3.3 for more information on safety and emergency considerations.

5.4.2. Shock and Overpressure[7]

Mechanical shock in an air cleaning system might be produced by explosion in an operating area of the building, by an earthquake, or by rapid compression or decompression of the air inside a system caused by sudden opening or closing of a damper, enclosure, or housing door. When pressure transients last for periods measurable in seconds, static pressure is primarily responsible for any destructive effect. For shocks that have a duration of only a few milliseconds with nearly instantaneous pressure rise - as occur in most chemical explosions - destructiveness is primarily a function of the momentum of the shock wave. Shocks produced by an earthquake or inadvertent opening or closing of a damper usually fall somewhere between these two extremes.

Protection of the filters and adsorbers against failure from shock can be accomplished by isolating them to prevent the transmission of forces to them and by increasing the shock resistance of ducts, housings, mounting frames, and equipment supports. The shock resistance of HEPA filters can be enhanced by face guards, and similar treatment may sometimes improve the shock resistance of prefilters. Most prefilters, however, probably have low shock and overpressure resistance, and a screen installed between them and the HEPA filter is recommended to prevent damage to the latter.

Tray-type adsorbers are generally of a robust construction and should be relatively unaffected by shock loading if properly installed. Filter and adsorber mounting frames and housings designed in accordance with the recommendations of section 4.1.2.2 should have adequate shock resistance for most applications.

Protection of the primary filter components from explosive shock can be achieved by providing sharp turns, heavy perforated plates. or cushion chambers in the ductwork to "snub" shock forces, and by using fast-acting isolation dampers. Although turning vanes, dampers, moisture separators, and prefilters may be damaged by a shock wave, they may also serve to attenuate its force to some degree and thereby

provide a measure of protection to the downstream filters and adsorbers. Damage to dampers, however, can result in an inability to control flows or isolate branch lines.

Explosion in an operating area of a building is probably the most likely type of shock-generating incident to be expected in a demil operation. A chemical explosion is similar to a rapidly burning fire and, therefore, can be arrested in a confined space if a suppressant or extinguishing agent can be introduced quickly enough.

At CAMDS the principal explosive hazard is provided for in another manner. During the punching and sawing operations in the ECC when explosions are most likely to occur, an explosion-proof door closes off the ductwork to protect it and the ensuing filter/adsorber banks from possible blast damage. This sequence lasts for about three minutes of every four minute cycle (assuming the ECC is at full operation), during which time no airflow occurs. No ventilation is required d[illegible] this period since the ECC is sealed completely airtight.

5.4.3. Fire and Hot Air[7]

Fire in gloveboxes and other toxic-agent containment facilities pose special difficulties to air cleaning and ventilation systems because of the need to contain contaminated air during the emergency. The release of contaminated smoke through a ruptured HEPA filter or other breach of the filtration system may have more serious consequences than any potential casualty losses from the fire itself.

Where it is possible to completely isolate and seal off the contained space within a building in which a fire occurs, the effect of fire on the filters and other air cleaning components may not be a serious matter. In most facilities, however, it is essential to maintain the differential pressure necessary to prevent backflow of contamination to occupied spaces of the building and to ensure filtration of contaminated smoke. Under the latter conditions, the effect of fire on the air cleaning system and its components becomes an important consideration. In many cases the final filters and fan, or a redundant set of filters and fan, must be operable during and following an emergency. If the building is zoned to control airflow from areas of less hazard to areas of greater hazard, differential pressures between zones must be preserved to prevent pressurization of the contained space in which the fire occurs and to prevent back-flow of contamination. Even when the ventilating system can be shut down in the event of a fire, protection of the filters/adsorbers is important to provide for cleanup of any contaminated air in the building after the fire has been extinguished.

Hazards to air cleaning units possibly arising from fire situations are: (1) heat and hot air can damage filters, ignite dust accumulated in ducts or filters, and distort metal parts to the point that filters are bypassed or fans and dampers are made inoperable; (2) sparks and burning trash can ignite dust and melt holes in the filter media; (3) smoke can plug prefilters and HEPA filters to the point that the airflow is seriously reduced and/or the filters are ruptured due to the increased resistance; (4) overpressure due to air expansion, coupled with smoke plugging, can lead to rupture of the filters; and (5) droplets of spray from fire-protection sprinklers or particles from other types of fire-extinguishing agents can perforate the filter medium, plug the filters, or lead to reduction of their structural properties.

The first line of defense against duct and filter fires is the development and enforcement of safe operating practices in the contained and operating spaces of the demil facility. This means eliminating one or more of the basic fire elements - fuel, ignition source, or oxygen. It includes (1) control over the kinds and quantities of combustible liquids and gases permitted for use in contained spaces; (2) control of hot plates, burners, furnaces, and other sources of heat or flame; and (3) possible inerting of the box or cell environment (especially gloveboxes) with nitrogen, argon, carbon dioxide, or other gas. Safe operating practices also include (1) the development and rehearsal of preplanned fire and damage-control procedures in the contained and occupied spaces of the facility, and (2) means for rapidly detecting and suppressing a fire (e.g., water deluge system).

5.4.4. Power and Equipment Outage[7]

Planning for emergency situations must provide for the probable occurrence of power and equipment (particularly blower) failures. Such failures, if not properly planned for, can result in a contamination hazard, particularly in buildings with zone ventilation where airflow must be maintained to preserve pressure gradients between zones and prevent backflow of contaminated air to occupied spaces. Possible emergency measures include redundant fans, redundant fan motors (perhaps served from independent power sources), and alternate power supplies (e.g., steam turbine or emergency diesel-electric generator). See section 4.1.2.10.2 for specific methods used at CAMDS.

When continuous airflow must be maintained, facilities for rapid automatic switching to an alternate fan, power supply, or emergency source, or to a standby air-cleaning unit, are essential. However, if brief interruptions of flow can be tolerated, manual switching may be permissible at less expense. In any event, visible and audible alarms should be provided, both locally and at a central control station, to signal the operator when a malfunction has occurred. In addition, indicator lights to show the operational status of fans and controls in the system should be provided in the central control room. Figure 5-2 shows a section of the control panel used at CAMDS for this purpose.

See sections 3.3 and 4.2.9 for discussions pertaining to redundancy.

5.5. Protection Requirements

5.5.1. Levels of Protection

The level of protection required by operating personnel in a toxic-chemical environment in a demil facility depends upon the potential hazard involved.* Basically, there are six levels of personal protective clothing available, ranging from Levels A through F. Definitions of the six levels of protection along with the specific clothing requirements for each level are given in reference 3 for nerve agents GB and VX and in reference 32 for mustard agents H, HT and HD. Additional information regarding protective clothing is given in references 34 through 38.

The general conditions under which various levels of clothing are worn by operating and maintenance personnel for toxic-agent protection in and around filter housings are summarized in Table V-2.

5.5.2. Demilitarization Protective Ensemble

The Demilitarization Protective Ensemble (DPE) has been proposed for approval to the U.S. Army Surgeon General for use in all chemical demil operations requiring Level A protection for GB, VX, and mustard. None of the references cited above cover this relatively new item In brief, the DPE consists of a reusable air-supplied respirator and a disposable ventilated outergarment. The respirator has a pressure-demand regulator and incorporates a full-face gas mask and 10-minute self-contained air supply for use during emergency egress only. The respirator system provides for automatic switchover to the emergency

*All personnel engaged in chemical demil work involving toxic operations must undergo physical examinations to ascertain that they are medically qualified to work in such areas. These examinations are conducted in accordance with the guidelines provided in reference 33.

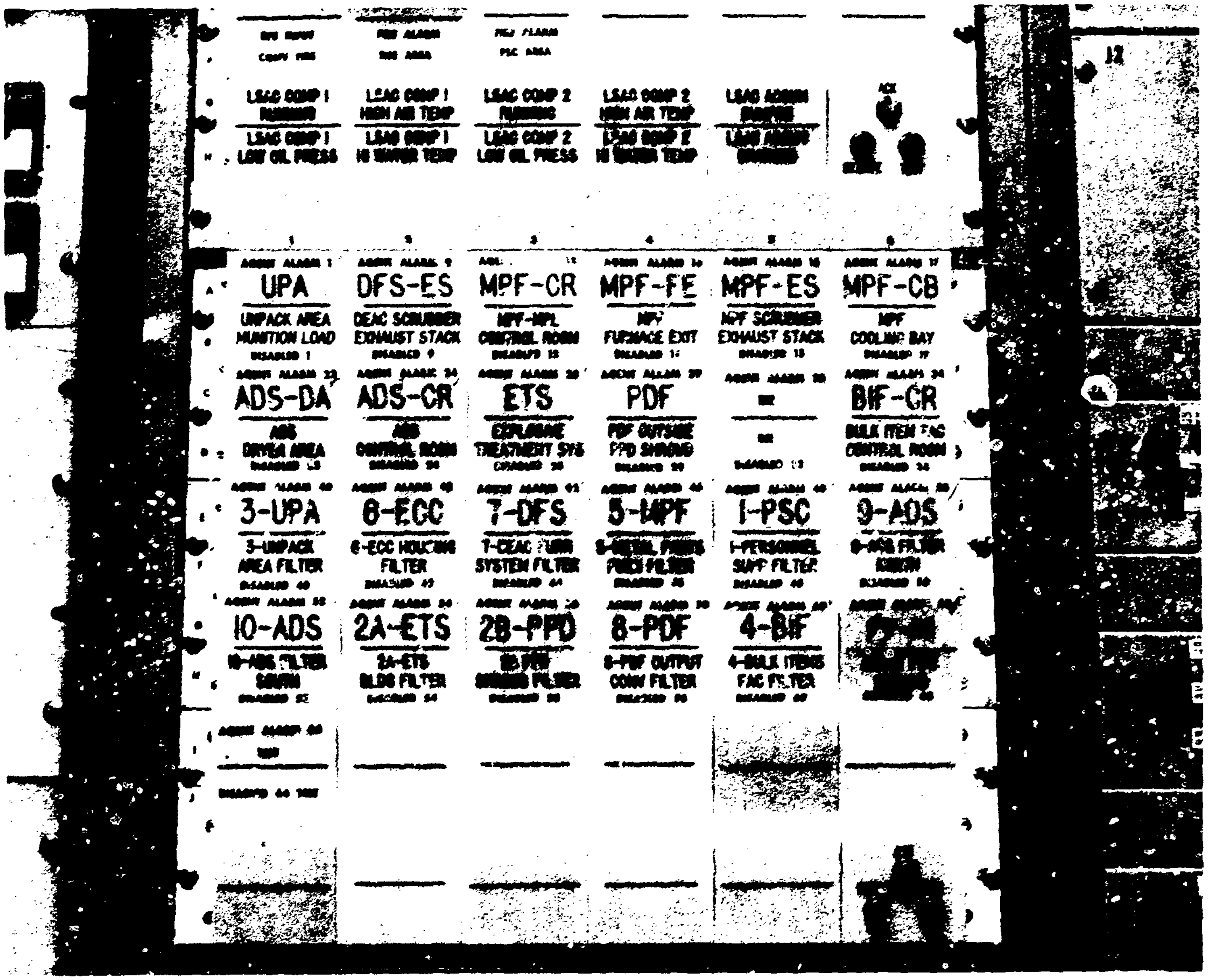

Figure 5-2. Section Of Central Control Panel At CAMDS Showing Operational Status Of Signals And Alarms

Table V-2.

Level Of Personnel Protection Required
For Chemical Demilitarization

Work Activity	Chemical Agent	Level of Protection Required	Remarks
Inspection, maintenance, and repair of components within filter housing upstream of second adsorber bank.	GB, VX, mustard	Level A	DPE suit is prescribed by the Surgeon General, Dept. of the Army, for wear wherever Level A protection is specified. (The M3 protective suit is no longer permitted except for depot munition surveillance and for emergency operations where speed and mobility are overriding considerations.)
Inspection, maintenance, and repair of components within filter housing downstream of first adsorber bank.	GB, VX, mustard	Level C	Level C attire for mustard calls for an M-2 butyl apron in addition to the clothing required for GB and VX.
Inspection, maintenance, and repair of components outside of filter housing.	GB, VX, mustard	Level F	Level F clothing is the same for GB, VX or mustard.

air supply when the main air-supply pressure drops to a prescribed level. A warning light in the face piece informs the wearer when he is consuming emergency air supply. The outergarment is a heat-sealed, one-piece garment fabricated from a plastic material resistant to agent penetration and to the deleterious effects of operational fluids, such as hydraulic and cutting oils and decontamination solutions.

Air from the main air supply is distributed to the outergarment extremities to provide cooling for the wearer. The worker wears a pair of M2A1 butyl rubber boots and a pair of M4 butyl rubber gloves over the DPE as part of the ensemble. Breathing air is supplied by means of a high-pressure umbilical connected to the air supply outlet. Although the making and breaking of air-supply connections within a toxic area is minimized, an inline filter is incorporated in the respirator to protect against agent incursion during hook-up. Specialized hose-handling equipment is also available to assist the worker in movement into, within, and out of the toxic environment. Provision is also included for communication between wearers and the command center.

5.5.3. Donning and Removing Protective Clothing

Personnel engaged in maintenance or similar activities must follow existing standing operating procedures for donning protective clothing and moving to the work site. When the worker completes his task and is ready to exit from the filter housing, certain other procedures apply depending on whether there is ready access to an airlock. (See section 4.2.3.) This is where the worker removes his contaminated apparel prior to returning to the point of origin. In the event there is ready access to an airlock system in an adjacent building, the normal procedure is to establish a "hot line" route for the workers to travel from the contaminated area to the airlock entrance. If an airlock is not available, use the procedure for establishing a "hot line" in an emergency. General procedures are given in FM 3-21[39].

6. BASIC MAINTENANCE AND STORAGE CONSIDERATIONS

6.1. Operator Responsibilities

Filter systems are designed to operate continuously with minimum maintenance. Once the system is operating, the following responsibilities are required of the operator:

1. Check airflow rates.

2. Check pressure drop across each particulate filter bank with pressure gages on instrument panel. A pressure drop in excess of prescribed limits (see section 6.4.1), in combination with low flow rate, indicates that the filters require changeout.

3. Check pressure drop across adsorber banks (this instrumentation optional). In normal operation there should be no increase in pressure drop over the initial value.

4. Record pressure drop across each bank daily to provide a history of the differential pressure of each stage. Visually inspect filters and adsorbers (if instrumented) whenever a major change in differential pressure is noted.

5. Check airstream between adsorbers for agent breakthrough, using the M8 detector and bubblers (see section 5.2). Any indication of such breakthrough is sufficient evidence that the adsorber needs replacement. In order to avoid premature replacement due to mechanical failure, the operator should perform in-service testing of the complete filter system at least once per year - in addition to regular monitoring procedures - in order to detect possible sources or causes of such failure. In any event, conduct in-service testing after the changing of any filter or adsorber to assure the quality of the new item and its installation. This testing is described in section 7.

6. Lubricate dampers and fans in accordance with manufacturer's recommendations. Also check and adjust fan-belt tension.

7. Set fan control meter to specified flow rate.

6.2. Preventive Maintenance Considerations[7]

In essence, preventive maintenance consists of those routine procedures, inspections, or monitoring performed by maintenance and operating personnel in an effort to keep a system operational. There are few preventive maintenance procedures to be exercised with chemical demil air-filtering systems because they are specifically designed with minimum service requirements in mind.

Dependability of operation is an important consideration in regard to the preventive maintenance of equipment for toxic agent applications. Even when the system is planned for part-time or intermittent operation, continuous operation may be required after the system goes into service and should be considered as the norm for design purposes. Savings in capital costs achieved through the specification of light-duty equipment are sometimes offset quickly by high maintenance costs after the system goes into service.

Roller bearings are preferable to journal bearings in fans and motors because of their superior operating characteristics, lower maintenance, and greater availability of replacements. Direct drive is generally more reliable than V-belt drive, although it is not as flexible for the adjustable flowrates often demanded by changing system requirements in demil facility applications. When V-belt drive is specified, at least 25% extra belt capacity should be required to carry the starting load of the motor; this extra capacity gives better wear characteristics and ensures continued operation in the event of partial belt failure.

Ideally, preventive maintenance is an operational factor whose cost can be minimized by good initial design and layout of ventilation and air-cleaning facilities. Inadequate attention to maintenance at the initial phase of the project can result in operating costs much higher than they should be. Two elements that largely influence the costs of this function are the accessibility of components requiring periodic test and service and frequency of filter and adsorber replacement. (See sections 4.1.1.3.3 and 4.1.1.3.4 for incorporation of these factors at CAMDS.) In systems that involve the handling of contaminated filters and adsorbers, the frequency of changing these components and the time to accomplish the change can be especially critical.

Maintenance of contaminated systems is much more costly than the same operations in noncontaminated systems because of the time required for personnel (1) to change into and out of protective clothing; (2) to decontaminate and clean up the area, tools, and equipment after the operation; (3) to dispose of contaminated filters; and (4) to accomplish personal decontamination procedures and be monitored by safety personnel. There is also the extra attention that must be given to filter or adsorber installation (as compared with common

air filters, for example). If the system does not meet specified test requirements after the change, the work must be repeated.

The fact that personnel may have to work in restrictive protective clothing, including full-face gas mask, also adds to the time required. Regardless of these inherently high time and cost factors, proper maintenance is essential to ensuring the reliability of the air-cleaning system, and it cannot be done properly unless appropriately designed and constructed physical facilities are available.

6.3. Inspection Considerations[7]

6.3.1. Procedures

6.3.1.1. Prefilters and HEPA Filters

Inspection of prefilters and HEPA filters must be made prior to their installation into the air cleaning system. Ensure that only the highest quality filters are used. Special care must be taken in removing the HEPA filters from their shipping containers since they are easily damaged by improper handling.

In visually inspecting new filters, use a light box with a strong lamp in a darkened room to examine both faces for breaks, cracks, or pinholes. Breaks or cracks in the medium usually show up on the surface edges of the filter pleats but often are not readily detected. Minor cracks can be of major importance. If the filter unit is installed with this pleat-edge damage, the cracks can be extended by air movement through the unit. After examining each channel, the inspector should examine the adhesive seal around the filter face to be sure that the seal is complete and unbroken. Each face of the filter should be examined in the same manner and with equal care.

After a thorough scrutiny of both faces, check the corner joints of the frame for sealing and tightness. Gasketing about the flanges of the frame should be inspected for full adhesion and good physical condition.

Exterior damage to several protruding separator edges in a small area does not influence HEPA filter efficiency if the medium is not mashed, punctured, or broken. Even though the medium may not be broken on one face, damage may occur at the opposite edge of the pleat on the other face. Large areas of mashed separator edges, even though the medium is not damaged, may obstruct the passage of air through the filter unit and thus reduce its life. Filter units which have been improperly stored should be inspected particularly for cracks along the adhesive seal, for extreme sags in pleats and separators, and for slits or breaks in the medium.

Although minor filter damage can be repaired with silicone rubber adhesive/sealant, it is considered economically unwise to do so in view of the cost, time, and reliability involved. It is better in most cases to reject the unit and substitute it with an acceptable one. This, of course, is a decision for the user to make as it also depends on the availability of acceptable filters to replace the damaged ones. Any repaired unit, however, must be retested to ensure that hidden damage does not exist which might reduce its filtering efficiency.

The repair of in-place or previously contaminated filters should not be attempted. Such filters should be removed and disposed of in accordance with regular procedures for handling contaminated items (see section 6.5).

6.3.1.2. Adsorbers

As with the prefilters and HEPA filters, the adsorbers must also be visually inspected prior to installation. Major areas of inspection are:

1. Retaining screens - should contain no punctures.
2. Face plate - should be tightly affixed to casing.
3. Adsorbent - should be tightly packed.
4. Gasket - should be rebonded if loose.

Except for tightening the face plate, no repairs are to be made to adsorbers, whether new or installed. Damaged new units are to be set aside for disposal, return to the manufacturer, or salvaging of the carbon adsorbent. Installed faulty adsorbers, whether contaminated or not, should be disposed of immediately.

6.3.2. Storage and Handling

In addition to thorough inspection of newly acquired filter units and components, proper storage and handling techniques must also be exercised to keep necessary repair actions to a minimum. The following procedures are recommended for achieving high standards of storage and handling:

1. Following receipt and inspection, each filter unit should be repacked carefully in the carton in which it was shipped and received. All packing material for internal strengthening of the carton and for protection of the filter unit should be replaced properly. Pleats of the filter unit should be positioned to conform to the orientation marking on the carton; this should be done routinely whether the filter unit is to be installed at an early date or stored.

2. Cartons of filter units and adsorbers should be handled and positioned in storage to conform to the printed directional arrows, and manufacturer's recommendations for storage heights should be followed. When recommendations are not available, cartons should normally be stacked not more than three units high.

3. Mixing other items and materials with filter units in storage should be avoided in order to prevent possible damage to the filter units. Recommended aisle widths consistent with good warehousing practice should be observed to reduce damage of filter units from materials-handling equipment and other traffic. Filter units should not be stored in locations where they will be exposed to dampness, excessive heat or cold, or rapidly changing temperatures.

4. Mechanical warehousing equipment is recommended for handling large quantities of filter and adsorber units. Skids and pallets should be used for movement, with the cartons placed on them so that their printed arrows point vertically. Chains, slings, and hooks must not be used.

5. In physically handling a packaged filter unit, make certain that the carton is picked up at opposite corners and deposited carefully on the floor or other surface. The carton should not be dropped or jarred. Any filter unit dropped, whether in the carton or not, should be reexamined for damage.

6. When a filter unit is lifted, it should be grasped only along the outer surface of the case. Even slight contact of fingers at almost any point within the case can puncture the filter medium. To avoid such damage when removing a filter unit from its carton, lift the carton off the filter unit rather than lifting the filter unit out of the carton.

7. Filter units should be kept in shipping cartons when moved from one location to another. When transferred for installation, the units should be unloaded at a point which, so far as practicable, will reduce physical handling. The filter units should continue to remain in cartons until ready for installation.

8. If for any reason an unpackaged filter unit must be placed with its face on the floor or other surface, the surface must be cleared of all objects or irregularities that might damage the filter pack.

6.3.3. Replacement Parts

The stockage levels of replacement parts required to support the filtering systems should be based on actual operating experience and/or manufacturer's recommendations. Information typical to the procurement of mechanical filters and adsorbers used in the CAMDS system is summarized in Table VI-1. Before procuring new filter units ensure that the framing of the units is compatible with the clamping mechanism of the filter housing (see Section 4.1.2.2).

Table VI-1. Information for Procuring Filter Units Based on CAMDS Experience

<u>Prefilters</u>

Manufacturer:	Flanders Filters, Inc.
Manufacturer's part number:	BC81-NL
ASHRAE efficiency:	80%
Initial resistance:	0.55 in. wg @ rated capacity
Capacity:	1,000 cfm per unit
Estimated replacement lead time:	6 weeks (for minimum quantity of one)
Estimated operating life:	Depends on operating conditions

<u>HEPA Filters</u>

Manufacturer:	Flanders Filters, Inc.
Manufacturer's part number:	7081-NL
Efficiency (per MIL-STD 282)[40]:	Not less than 99.97%
Initial resistance:	1.0 in. wg @ rated capacity
Capacity:	1,500 cfm per unit
Max. operating temperature:	250°F
Max. operating relative humidity:	100%
Estimated replacement lead time:	6 weeks (for minimum quantity of one)
Estimated operating life:	Depends on operating conditions

<u>Adsorbers</u>

Manufacturer:	CTI-Nuclear, Inc.
Manufacturer's designation:	Type CS-800 special adsorbent
Specification:	AACC Standard CS-8[10]
Initial resistance:	0.7 in. wg @ rated capacity
Capacity:	333 cfm per tray
Estimated replacement lead time:	16 weeks (for minimum quantity of 100)
Estimated operating life:	Depends on operating conditions

6.4. Replacement of Filters and Adsorbers

6.4.1. When to Replace[4]

Differential pressure is a primary factor in determining replacement of mechanical filters. A series of five differential pressure gages are mounted in the instrument panel of each filter housing. Each gage indicates the differential pressure across one stage of the system. Any large increase or decrease from the initial reading indicates that the bank is functioning improperly. Values recommended for replacement of CAMDS filters are given in Table VI-2.

Table VI-2. Recommended Differential Pressure Values for Filter and Adsorber Changeout

Type Filter	Clean Filter Differential Pressure[(a)] (in. wg)	Normal Differential Pressure for Changeout (in.wg)	Maximum Differential Pressure for Changeout (in. wg)
Prefilter (Type BC81-NL)	0.55	2.0	5.0
HEPA Filter (Type 7081-NL)	1.0	3.0	10.0
Adsorber (Type CS-800)	0.7	Not Applicable	Not Applicable

(a) These are manufacturer's values. See Table IV-3 for actual values measured at CAMDS.

Operation at airflow levels below the manufacturer's rated capacity extends filter life and reduces filter change frequency. When airflow exceeds the manufacturer's recommendations by more than about 15 to 20%, the dust-loading rate begins to increase exponentially with arithmetic increases in airflow. Changeout of the filters at this increased level is not necessary because pressure drop increases of up to several times the normal value can be tolerated without affecting filter efficiency as long as the rated airflow of the filter can be maintained by the blower. (See also sections 4.1.3.1.11 and 4.1.3.2.6.)

A sharp decrease or increase in pressure drop may also be caused by a faulty sensing gage rather than a filter problem. The possibility of a malfunctioning instrument should be checked before initiating filter changeout.

Changes in differential pressure across adsorber banks, if monitored, are normally not a cause per se for adsorber changeout. Adsorbers should maintain a constant pressure-drop value since the adsorption by carbon of gaseous material does not produce clogging nor otherwise significantly increase the differential pressure as long as the mechanical filters upstream remove all particulate matter. It is recommended, however, that any variations in pressure drop in the adsorbers on the order of 20 percent or more be investigated immediately as a potential problem area.

Under normal operating conditions where agent releases are minimal, adsorbers retain their adsorptive capabilities for extended periods of time. Adsorber life expectancy, however, can be reduced by several factors, namely:

1. Excessive exposure to water, water vapor, and certain chemicals which, by themselves or their reaction products, exert a degrading effect on the carbon adsorbent.

2. Mechanical failure due to rupture, dust buildup, or formation of carbon fines.

3. Agent overload caused by equipment malfunction or gross agent spill.

First-bank adsorbers require changing (1) when the M8 detector/alarm sampling between the banks exceeds its sensitivity or threshold detection level (see Table V-1), or (2) when the bubblers exceed the applicable maximum allowable concentration (see Appendix A). See section 5.2 for the monitoring procedure to be followed in case of a warning of adsorber breakthrough.

6.4.2. Replacement Procedures

6.4.2.1. Discussion[7]

Replacement of contaminated filters and adsorbers entails many steps that must be performed sequentially. Each step must be carefully planned and completed in a methodical manner to preserve containment of the system. Close coordination between maintenance and operating personnel is necessary (1) to establish a mutually satisfactory date and time for the component change, (2) to identify the components and systems involved, (3) to procure the necessary materials, (4) to schedule personnel, and (5) to avoid conflicts and misunderstandings that can lead to accidents or toxic exposures.

When the necessary materials and tools are ready and all personnel have been instructed in their specific duties, final permission must be secured from the responsible operator to stop or alter the airflow so changeout can be accomplished. The flow path of the exhaust system should be thoroughly understood, and persons responsible for related exhaust systems that will be affected must be forewarned. For instance, if two exhaust systems manifold to the same blower, final filters, and stack, the removal of one system from service for a filter/adsorber change will necessitate shutdown of the other system. Safety clothing and respiratory protection must be worn as directed by safety personnel.

Under normal conditions, it should be necessary to replace only one filter/adsorber bank at a time within the same housing. In those situations where two or more banks must be simultaneously changed, the recommended procedure is to replace the most contaminated item first and then the least contaminated. In most cases, the order of changeout - assuming all three components are involved, would be (1) prefilter, (2) HEPA filter, and (3) adsorber. If the first adsorber bank must be replaced, no action is taken regarding the second (redundant) adsorber bank, which remains undisturbed.

There are three basic procedures for replacing contaminated filters and adsorbers, namely:

1. Method A, Bag-In Bag-Out Procedure (for type I filter housings).
2. Method B, Bag-Out Procedure (for type I filter housings).
3. Method C, Walk-In Procedure (for type II filter housings).

These are described in the following sections. The changeout of particulate filters in type III filter housings (containing nonremovable adsorbers) is the same as described for Method C; an adsorbent removal method has been developed by the nuclear industry for these adsorbers but is not included here since it has not yet been tried in a demil application.

6.4.2.2. Method A, Bag-In Bag-Out Procedure*

Type I filter housings are designed to permit filter and adsorber replacement by reaching in from the outside, thereby eliminating the need for personnel to enter the housing and exposing themselves to the risk of contamination. This procedure, originated by the nuclear industry, uses plastic bags to enclose the housing opening and filters or adsorbers during removal and replacement. The procedure, hereafter referred to as Method A for brevity, is described pictorially in figures 6-1 through 6-8.

*This is the recommended procedure for use in the nuclear industry.

During this procedure, the blower is shut off; however, because of the redundant filter system concept (figure 4-49), it is possible that a reverse airflow could develop within the housing and cause the bag mounted over the access opening to be sucked in when the door is removed and the bag untied. To prevent reverse flow, isolation dampers should be installed in the ductwork upstream of the filters to block off the air and isolate the housing from the rest of the ventilation system during the change.

The changeout bags should be made of clear plastic film to enable the worker to see what he is doing. Since the bags can easily tear or abrade when used with metal-cased filters or adsorbers, strong material is required. The type of bag used at CAMDS is described in the purchase description as:

> "Bag, polyvinylchoride, 11 mil, 94-96 inches long with a butyl rubber or bungee-cord O-ring seal around the open end. The bag shall be sized to permit the end to go over a flanged opening approximately 124 in. in circumference. The O-ring is to be sized to permit the bag to seal snugly to the flange. The bag is to be fabricated in such a manner that it shall provide a vapor-tight enclosure when the open end is heat sealed".

The specific procedure for the removal and replacement of spent filters or adsorbers employing Method A, consisting of 15 steps, follows:

<u>Step 1.</u> The normal configuration of the system prior to changeout is shown in figure 6-1. The element (filter or adsorber) is installed and held in place by four toggle clamps. A plastic bag, sealed by an O-ring to the flange of the access door, is already in place from the last element change. The bag is folded so as to remain out of the airflow path and within the housing door flange space. The access door is installed on the flange with the bag held in place between the door and the flange to form a leaktight closure inside the door.

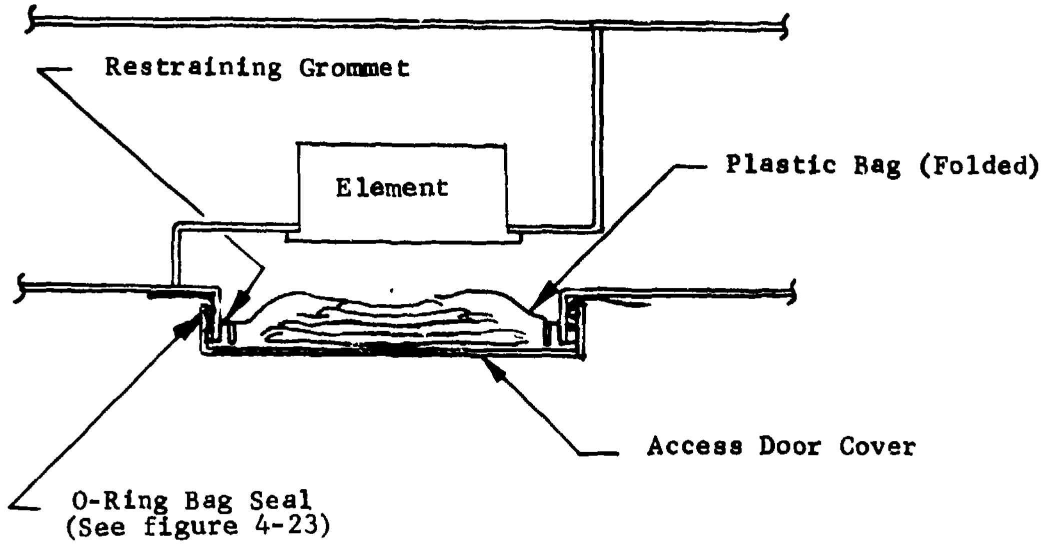

Figure 6-1. Operating Configuration With Element In Place, Bag-In Bag-Out Procedure

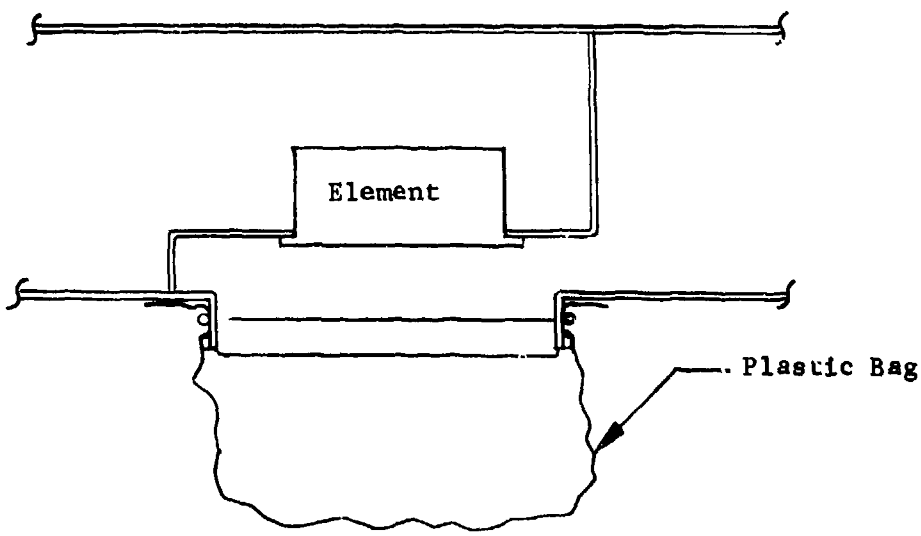

Figure 6-2. Access Door Removed And Bag Restraint Removed

Step 2. Turn off blower and lock power disconnect in OFF position.

Step 3. Remove access door and unfold plastic bag as shown in figure 6-2. Level C protective clothing is required at this point. Release toggle clamps holding element by grasping handles through plastic bag and moving them to open position.

Step 4. Withdraw spent element into plastic bag as shown in figure 6-3.

Step 5. Make two parallel heat seals* about 1/2 in. apart in plastic bag between element and housing flange, isolating contaminated element, then cut bag between seals (figure 6-4).

Step 6. Attach new bag containing clean element over old bag stub on access door flange. Install new bag so that O-ring seal of old bag is inside new bag (figure 6-5).

Step 7. Working through new bag, pull old bag stub off flange and move it into back of new bag make two parallel heat seals about 1/2 in apart to isolate bag stub, then cut bag between heat seals (figure 6-6).

Step 8. New element is now ready for installation. Verify that it has been inspected and accepted for use before placing it in bag.

Step 9. Position new element in rack and lock into place with four toggle clamps. Insert prefilters and HEPA filters so that pleated folds are vertical. Verify that filter gasket is compressed at least 50%; adjust toggle clamps, if necessary, to provide more gasket compression.

Step 10. Fold plastic bag to preclude interference with air stream in filter plenum. This is done by drawing bag taut across flange with excess bag on outside, then folding bag back and forth to fit within flange opening. Bag is held in this position with piece of cord as shown in figure 6-7.

*For all sealing operations, the use of a scissors action, cantilever-type heat sealer is recommended. A roll-type sealer is not practical for this application. A thermal-impulse heat sealer, manufactured by Vertrod Corp., Brooklyn, N.Y., is used at CAMDS.

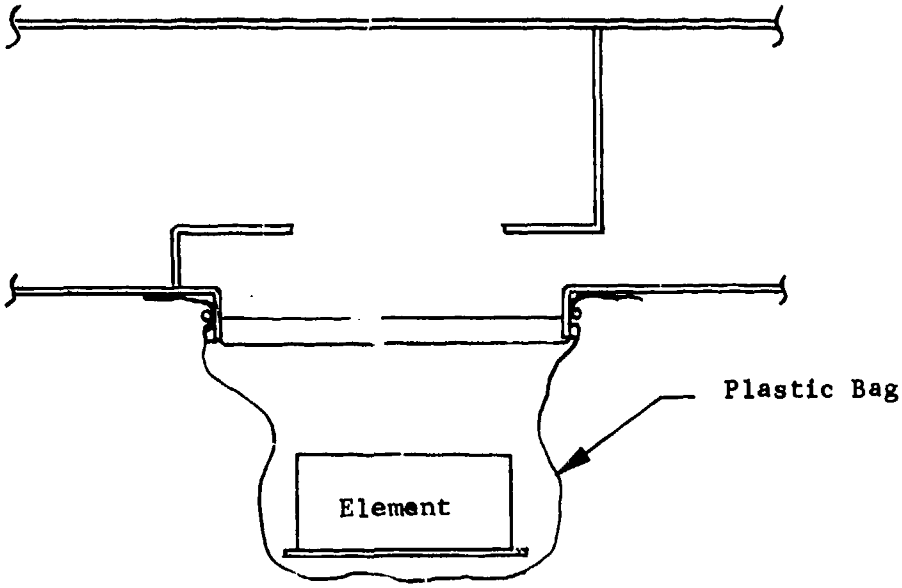

Figure 6-3. Dirty Element Withdrawn Into Bag

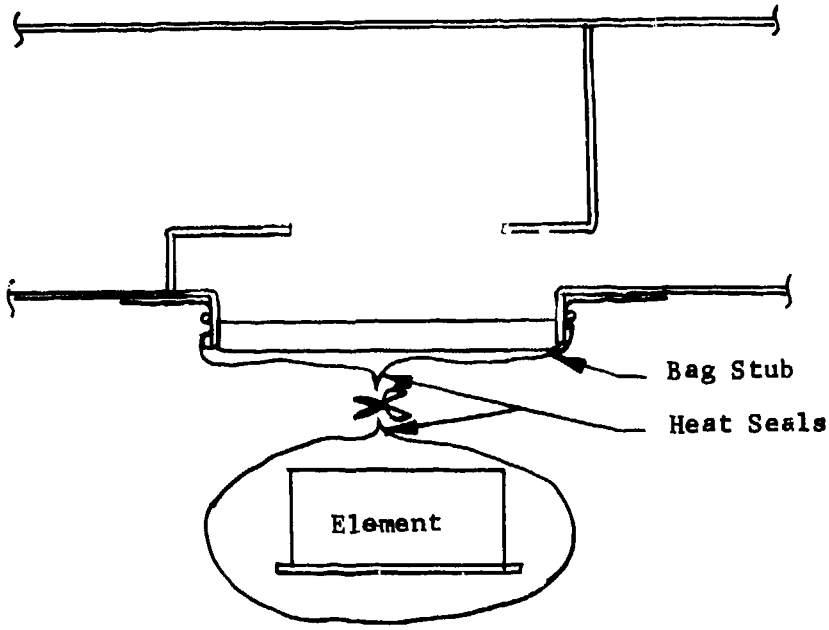

Figure 6-4. Dirty Element Separated From System

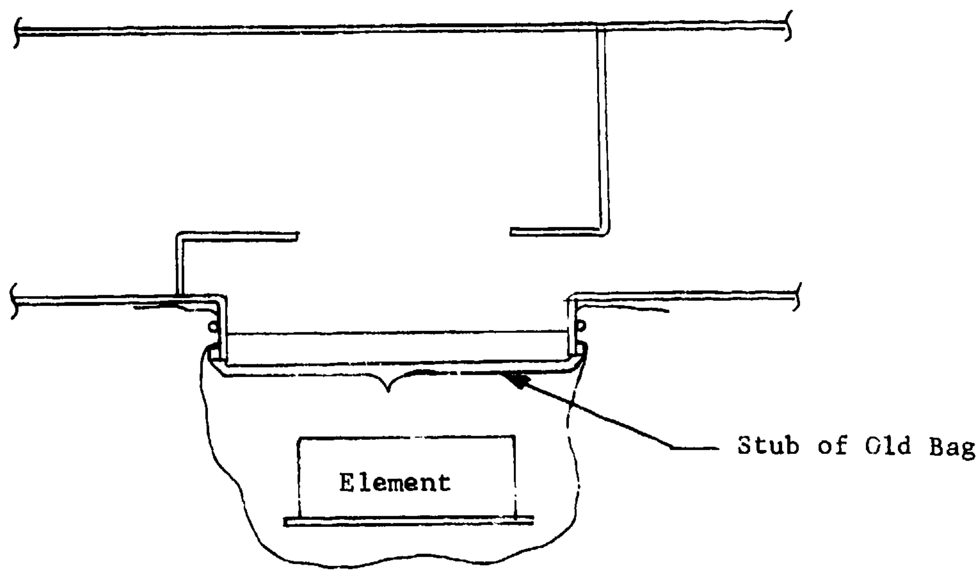

Figure 6-5. New Element In New Bag Sealed To System

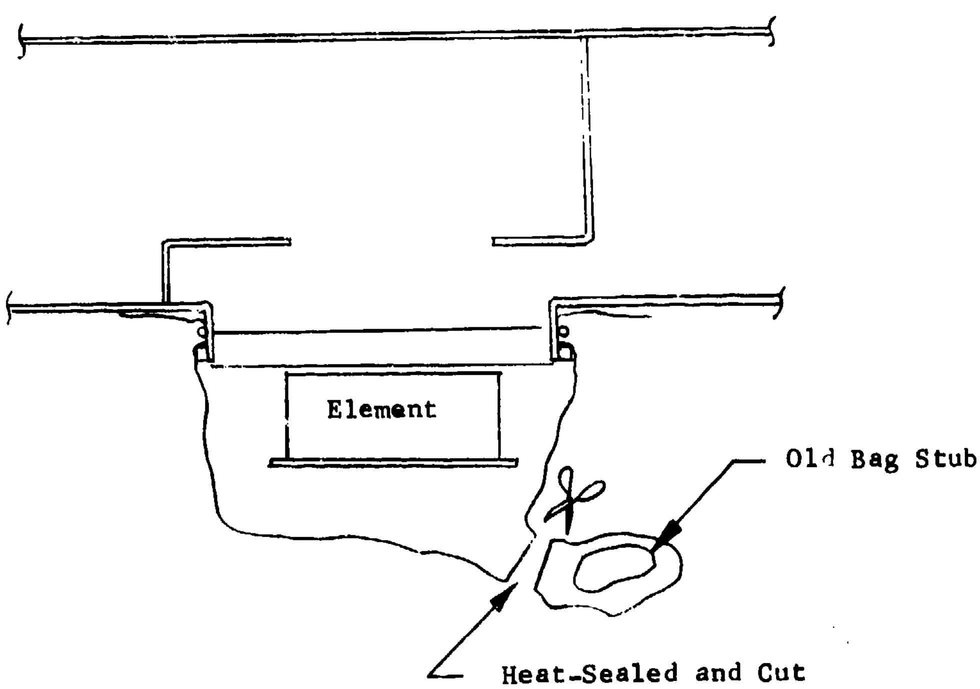

Figure 6-6. Old Bag Stub Removed

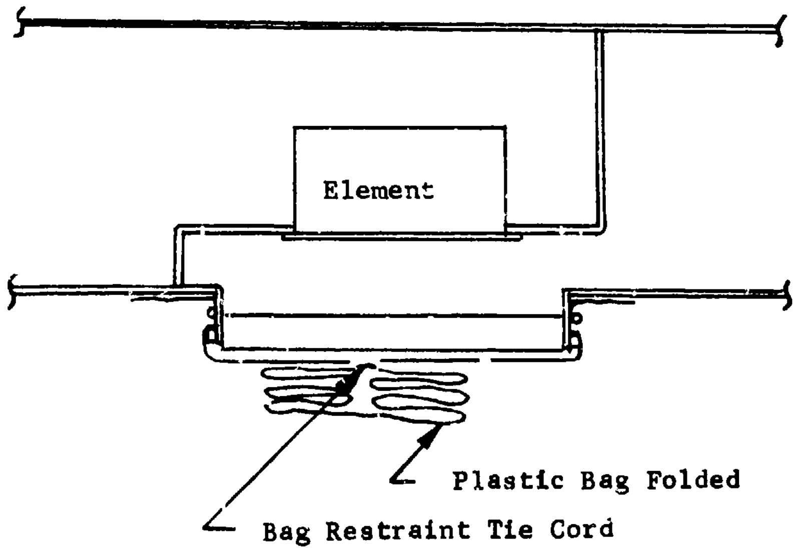

Figure 6-7. Element In Place With Bag Folded

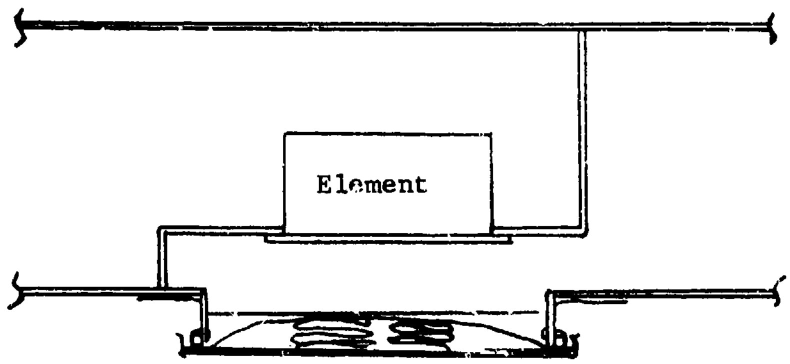

Figure 6-8. Operating Configuration With New Element In Place

Step 11. Replace access door over plastic bag and secure it in place (figure 6-8).

Step 12. Open isolation damper, unlock power disconnect, and turn on blower to verify that bag is sufficiently taut to preclude interference with airstream.

Step 13. Check area for contamination; decontaminate if necessary.

Step 14. Remove bagged elements and old bag stub for disposal. (See section 6.5.)

Step 15. Make in-place DOP test on filters and freon test on adsorbers as described in section 7 and Chapter 8 of reference 7.

6.4.2.3. Method B, Bag-Out Procedure*

As indicated in section 4.1.2.3, a problem developed at CAMDS with bag deterioration as a result of exposure to sunlight of that portion of the emplaced bag extending outside the housing. Therefore, it was decided to do away with the permanently emplaced-bag concept (i.e., the bag-in part of Method A) and insert the bag at the time of replacement. This led to the introduction of Method B, the bag-out procedure.

The specific procedure for the removal and replacement of spent filters or adsorbers employing Method B, consisting of 13 steps, follows:

Step 1. The normal configuration of the system prior to changeout, as shown in figure 6-9, is similar to the configuration of figure 6-1 except there is no plastic bag installed around the flange.

Step 2. Turn on blower and adjust so that minimum airflow of 150 fpm is maintained across access opening (to provide negative pressure to prevent escape of contamination); remove access door to break seal (figure 6-10). There will be some difficulty at first, but once seal is broken, door can be easily removed.

*This is the approved procedure for use at CAMDS; it is not used in the nuclear industry.

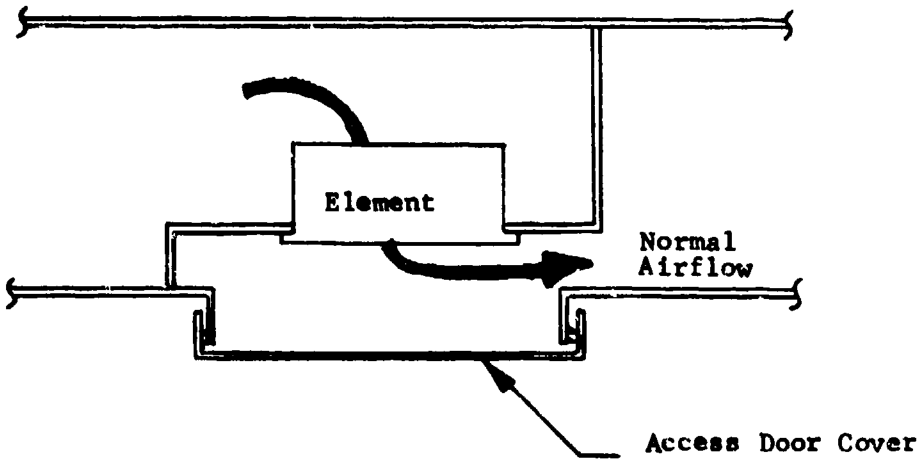

Figure 6-9. Operating Configuration With Element In Place, Bag-Out Procedure

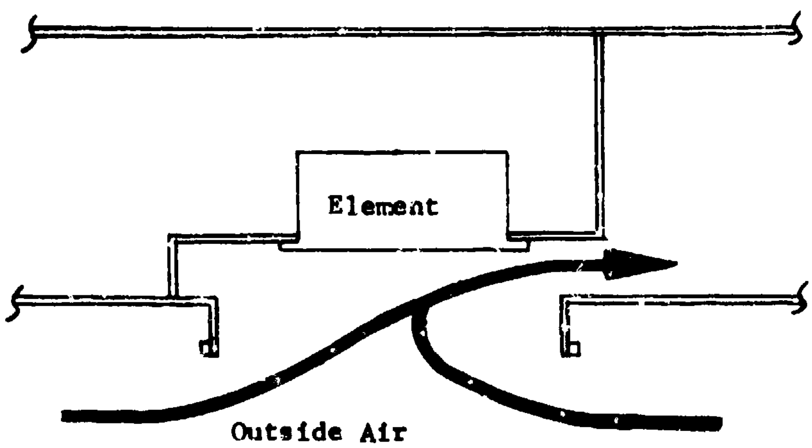

Figure 6-10. Access Door Removed

__Step 3.__ Attach bag over access door flange and seal with O-ring (figure 6-11).Turn off blower as soon as bag is secured to prevent bag from being sucked into housing.

__Step 4.__ Release toggle clamps holding filter or adsorber by grasping handles through plastic bag and moving them to open position.

__Step 5.__ Withdraw spent element into plastic bag as shown in figure 6-12.

__Step 6__. Make one heat seal in plastic bag (figure 6-13).

__Step 7__. Turn on blower and remove entire bag (figure 6-14). Verify velocity of inward airflow through door (should be 150 fpm).

__Step 8.__ New element is now ready for installation. Verify that it has been inspected and is acceptable for use.

__Step 9__. Position new element in rack and lock in place with four toggle clamps. Insert prefilters and HEPA filters so that pleated folds are vertical (figure 6-15). Verify that filter gasket is compressed at least 50%; adjust toggle clamps, if necessary to provide more gasket compression.

__Step 10__. Replace access door and secure it in place (figure 6-16).

__Step 11__. Check area for contamination; decontaminate if necessary.

__Step 12__. Remove bagged elements for disposal. (See section 6.5.)

__Step 13.__ Make in-place DOP test on filters and freon test on adsorbers as described in section 7 and Chapter 8 of reference 7.

6.4.2.4. Method C, Walk-In Procedure

With the larger type II filter systems, the replacement of filters and adsorbers is accomplished by a "walk-in" procedure, hereafter referred to as "Method C." Here the changeout personnel, while wearing Level A protective clothing, actually enter the filter housing instead of reaching in from the outside.

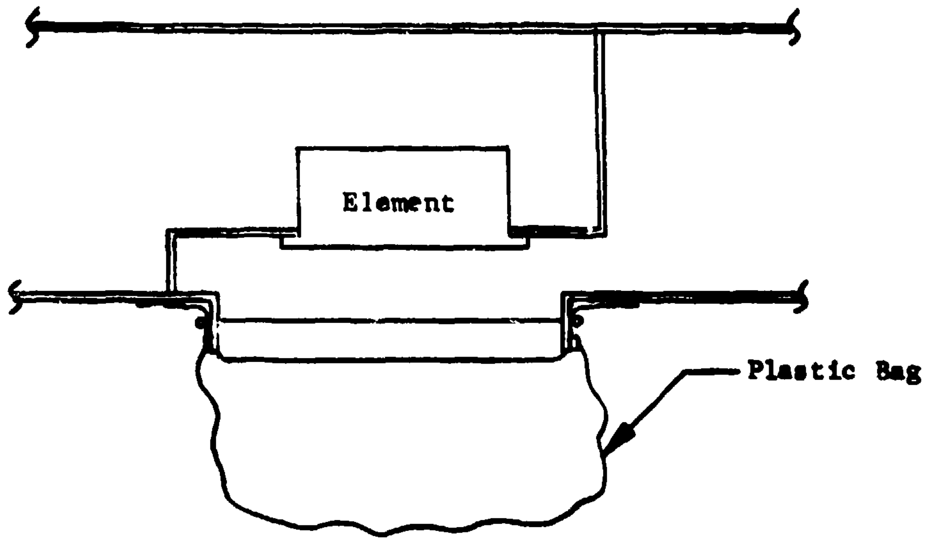

Figure 6-11. Bag Installed Over Access Door Flange and Blower Turned Off

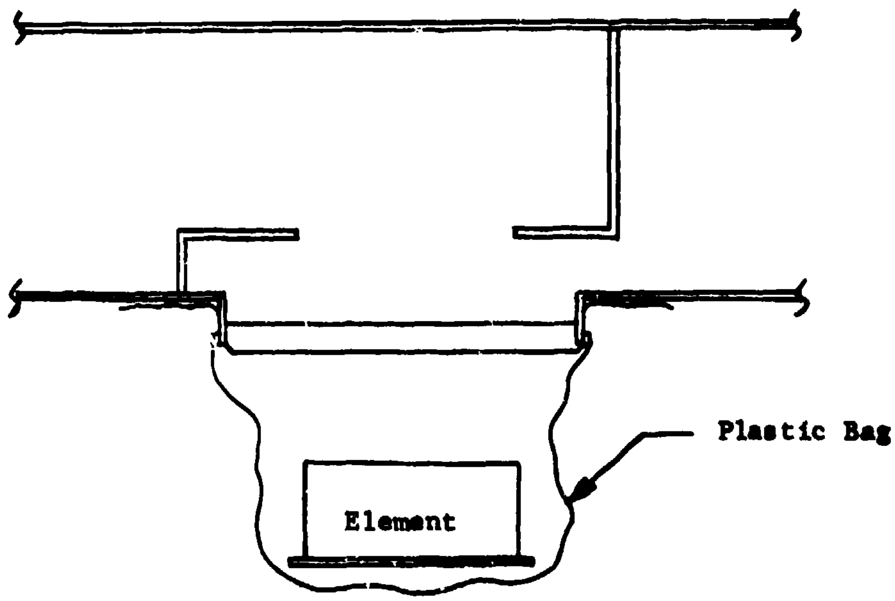

Figure 6-12. Dirty Element Withdrawn Into Bag

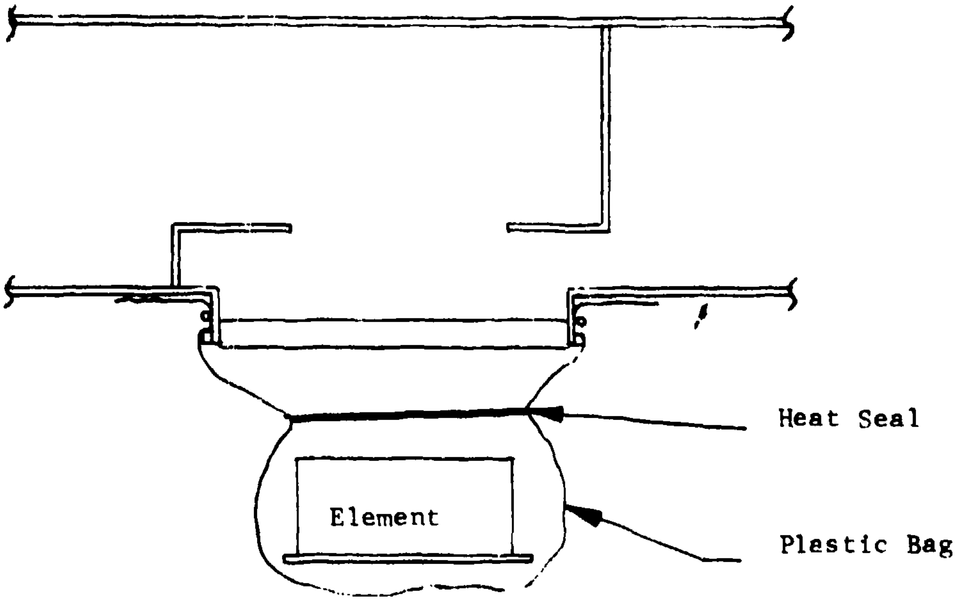

Figure 6-13. Dirty Element Sealed In Bag

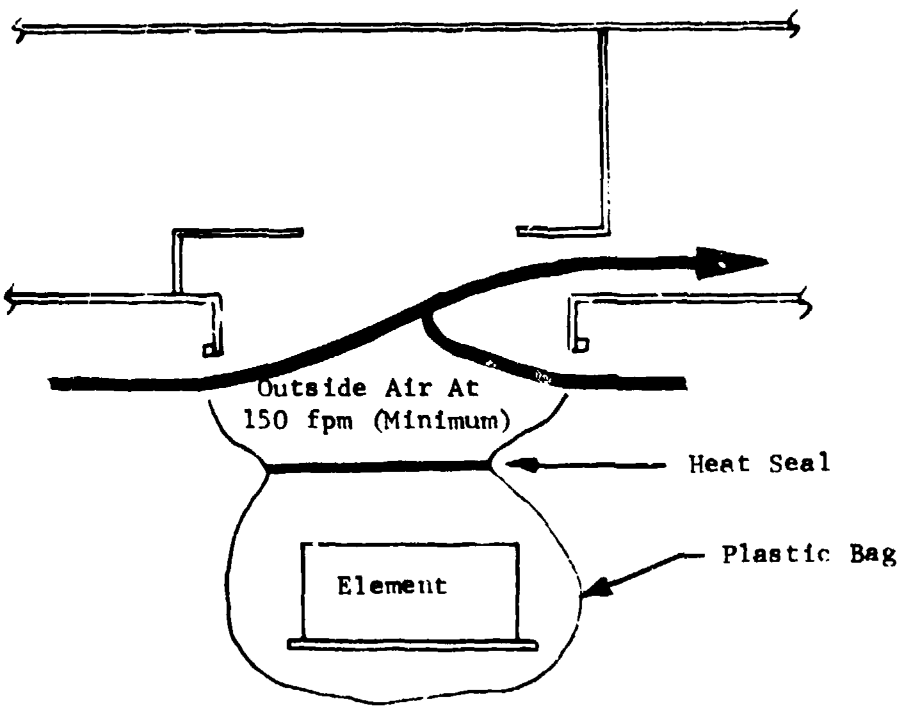

Figure 6-14. Bag Containing Dirty Element Removed From Access Door and Blower Turned Off

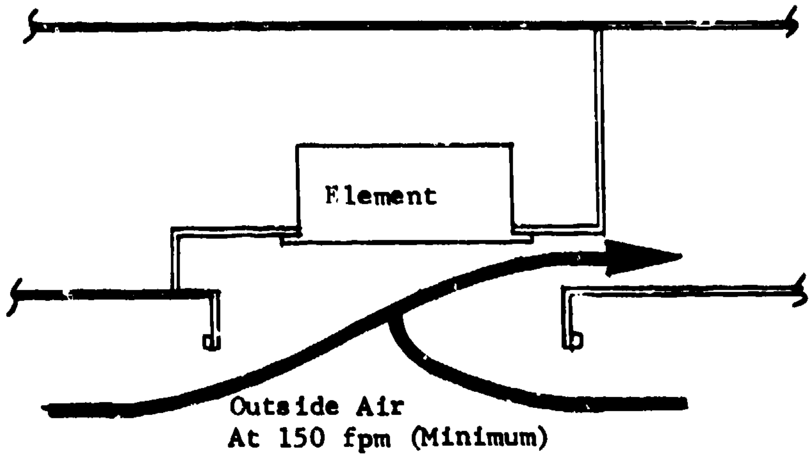

Figure 6-15. New Element Installed

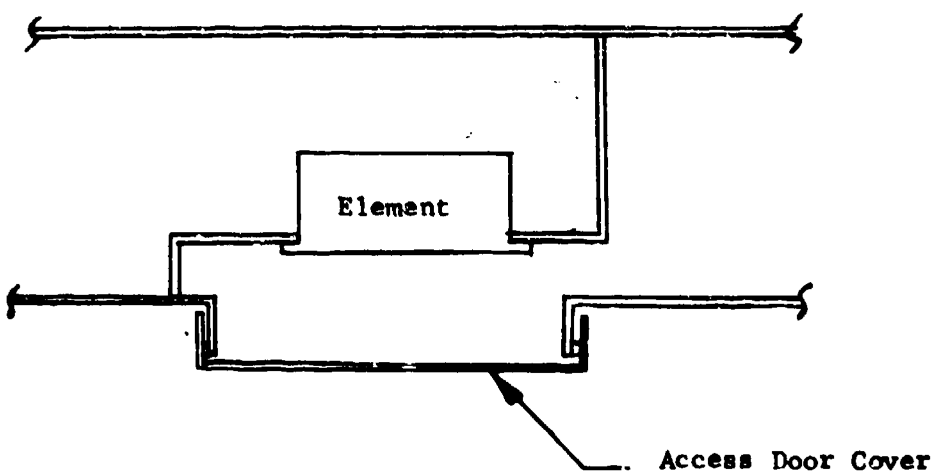

Figure 6-16. Operating Configuration With Element In Place

The specific procedure for the removal and replacement of spent filters or adsorbers employing Method C, consisting of 16 steps, follows:

<u>Step 1</u>. Establish "hot line" procedure as outlined in reference 39.

<u>Step 2</u>. Turn blower down (do <u>not</u> shut off) until door seal can be easily broken and housing door opened. Once door is slightly open, increase blower again to airflow that will maintain a velocity of at least 150 fpm (approximately 2,000 cfm) through the door.

<u>Step 3</u>. Turn on housing interior lights.

<u>Step 4</u>. Two operators (in Level A protective clothing) fully open housing door, enter housing, and, using an M8 detector, check for contamination in particulate filter area. If contamination is detected, scrub area with appropriate decontamination solution (18% NaOH for GB, 10% HTH for VX or H). Verify that floor drain is open and connected to a sump tank or container before starting decontamination procedure.

<u>Step 5</u>. After decontamination, scrub area with water to remove residual decontamination solution.

<u>Step 6</u>. Release spent element by backing off spin handles until clamp can be turned to clear flange of filter case. There are four clamps per element.

<u>Step 7</u>. Remove element from rack and place in plastic bag.

<u>Step 8</u>. Heat-seal plastic bag and pass to workman outside filter housing for handling in accordance with "hot-line" procedure.

<u>Step 9</u>. Repeat steps 6 through 8 until all elements in bank have been removed.

<u>Step 10</u>. New element is now ready for installation. Verify that it has been inspected and found acceptable for use.

<u>Step 11</u>. Workman on outside of housing removes new element from carton (exercising precautions given in section 6.3.2) and hands it to workman inside housing. If new element is removed from carton before starting changeout, bagged spent element

can be immediately placed in this carton for disposal.

Step 12. Install new element in bank and lock in place with four spin handles. Insert HEPA filters so that their pleated folds are vertical. Verify that filter gasket is compressed at least 50%; adjust toggle clamps, if necessary, to provide more gasket compression.

Step 13. Repeat steps 10 through 12 until all elements in a bank have been replaced.

Step 14. Secure access doors and turn off blower.

Step 15. Make in-place DOP test on filters and freon test on adsorbers as described in section 7 and Chapter 8 of reference 7.

Step 16. Close all access doors and clear "hot-line".

6.5. Disposal of Spent Filters

The filters and adsorbers of a toxic-agent ventilation system do not decontaminate or neutralize contaminants but simply collect them. Therefore, these contaminated spent elements must be disposed of with care to prevent a hazard to personnel or a release of contamination. DARCOM Regulation 385-102[3] states that incineration or neutralization are the only methods currently acceptable for destroying filters contaminated with toxic chemicals.

It is planned to dispose of CAMDS filters by incineration in the Metal Parts Furnace (MPF). The MPF is a high-temperature hearth furnace for the heat treatment of hardware components to ensure the destruction of all traces of toxic chemicals. Furnace gases are passed through an afterburner and a scrubber system before discharge to the atmosphere. The MPF is also used to incinerate mustard agents directly from munitions and to dispose of contaminated dunnage.

The normal operating temperature of the MPF is approximately 600°C (1100°F), while its afterburner operates at 1600°F (871°C). These temperatures are sufficient for destroying toxic agents, the decomposition temperatures of which are as follows:[41]

<u>GB</u> - Complete decomposition after 2-1/2 hours at 150°C (approx. 300°F)

<u>VX</u> - Half-life decomposition:

36 hours at 150°C (approx. 300°F)

1.6 hours at 200°C (approx. 400°F)

4 minutes at 250°C (approx. 500°F)

36 seconds at 295°C (approx. 560°F)

<u>Mustard</u> - Decomposition at 140° to 177°C (approx. 300° to 350°F)

The contaminated elements, still sealed in plastic bags and cartons after removal from the housing, are placed on trays and fed by roller into the furnace. Residence times and temperature parameters for incinerating the carbon adsorbent and metal hardware are currently under study to determine if any of these components can be economically salvaged.

7. TESTING

There are five general types of testing of interest in chemical demil air-cleaning and ventilation systems. An additional phase, prototype qualification testing by vendors, is beyond the scope of this handbook. Tests of particular interest are:

1. Initial acceptance testing
2. Preoperational testing
3. Air balancing
4. Systems integration testing
5. In-service testing

All of these test procedures, which are described in the following sections, should be preceded with a careful visual inspection of all items to be checked during the tests.

7.1. Initial Acceptance Testing

New HEPA filters and adsorbers are subjected to post-installation acceptance tests. The specific objectives of these tests are:

1. Verify downstream leaktightness of the two HEPA filter banks normally installed in each filter housing, based on an upstream challenge with DOP (dioctylphtalate) smoke.

2. Verify downstream leaktightness of the two adsorber banks normally installed in each filter housing, based on an upstream challenge with Refrigerant-12 freon gas (dichlorodifluoromethane).

DOP testing verifies the integrity (leaktightness) of the installed filter system and of the filters themselves, which were previously efficiency-tested by the manufacturer. It is conducted in accordance with section 10 of ANSI N510[8] and is discussed in detail in section 8.3.1 of reference 7. Freon testing is conducted in accordance with section 12 of ANSI N510 and is discussed in section 8.3.2 of reference 7. It measures the overall integrity of the installation and the quality of manufacture of the adsorbers. No specific tests are required on prefilters.

The test plan used for the acceptance testing of CAMDS air filter systems is given in reference 42.

7.2. Preoperational Testing

After completion of the initial acceptance tests, each complete filter system undergoes a series of preoperation tests to ensure that the entire system is ready for operation. The specific test objectives

are:

1. Verify accuracy of filter system flow instruments, controls, and alarms as compared to readings obtained with calibrated air-flow instrument.

2. Determine pressure drop across each bank of prefilters, HEPA filters, and adsorbers as well as across entire filter system at initial (clean) condition and at five subsequent arbitrarily-selected higher static-pressure values.[42]

3. Verify the capability of the blower unit to maintain the specified volume airflow when the filter system's resistance is increased by 125% over the initial (clean) pressure drop.

4. Determine amperage, rpm, discharge, and ΔP characteristics of the fan motor.

7.3. Air Balancing

Once the filter system has been verified as being operational and all ductwork and dampers are installed, the air balancing of the ventilation system for each area may be performed. The system is balanced by adjusting airflow and differential pressures to meet the general criteria given in section 3.2 for determining ventilation rates.

The specific objectives of air balancing are:

1. Adjust dampers to establish desired system flows and pressures.

2. Verify airflow and differential pressure capabilities of the various ventilation subsystems in both toxic and non-toxic areas.

3. Verify airflow from less contaminated areas to more contaminated areas.

4. Assess performance of the system's fail-safe features, power-off operation, interlock devices, automatic and manual controls, annunciators, and alarms.

5. Evaluate overall performance of the system in accordance with design specifications.

The ventilation system is generally accepted after required adjustments are made and the tests successfully demonstrate that all airflows and differential pressures meet design specifications.

Air balancing is normally a one-time test. Since it is critical to safe operation and is a relatively complex effort, it is advisable to consider the services of an Air Balancing Institute-certified contractor who specializes in this type of activity. In any event, it is mandatory that air-balancing procedures for demil applications be approved by AEHA.

The air-balancing plan used at CAMDS is given in reference 11.

7.4. Systems Integration Testing

Systems integration testing involves the entire demil facility. These tests evaluate the operational performances of all subsystems operating in response to simulated abnormal and upset conditions, possible equipment or power failures, and other anticipated problems. The specific objectives of the tests are to assure that the following operational characteristics are met:

1. Airflow capacity
2. Differential pressure maintenance
3. Fail-safe features
4. Power-off operation
5. Interlock performance
6. Automatic and manual controls
7. Annunciator and alarm performance

Detailed procedures for systems integration testing used in the CAMDS facility are presented in reference 11.

7.5. In-Service Testing

The objectives of post-operational in-service testing are to determine the continuing serviceability and integrity of each filter system (1) after a specified period of operation, (2) after making critical repairs, and (3) after replacing filters or adsorbers. This test is also used to verify that the filter system remains air tight and that it continues to meet the prescribed performance criteria for removal of contaminants.

An in-service test for each filter system should be conducted at least once per year regardless of whether the system, during that year, operated part time, on a normal work schedule, or was essentially inactive. In-service testing is also necessary after any type of filter or adsorber changeout. Subsequent testing need not be repeated until one year after filter/adsorber replacement.

The test procedures are the same as the initial acceptance tests given in section 7.1. Details relative to the test procedures and data handling used at CAMDS are described in reference 43.

7.6. CAMDS Test Experience

In evaluating the nuclear-concept filter system designed for CAMDS use, it was necessary to generate life data (i.e., capacity of the cells to retain a specified quantity of chemical agent) since such information was not otherwise available from the nuclear industry. Therefore, life testing was initiated at CAMDS to verify that the system could perform as required. Three separate sets of tests were conducted. The first set was performed on type II adsorber cells prior to the preparation of a procurement specification; the second set involved type II cells supplied as part of the first-article testing of the procurement specification; and the third set pertained to a completely installed filter system at the CAMDS site.

Set No. 1 [44]

A series of six type II adsorber cells,* containing coconut-base activated carbon, were tested with high concentrations of agent GB. One additional cell was tested with a high concentration of VX in aerosol form. The XC10-1 carbon filter cell (the basic adsorber component in the Army CBR filter unit) was also tested to provide a basis for comparison. Testing was conducted at the U.S. Army Edgewood Arsenal toxic test chamber during the period October 1973 through May 1975. The test results indicated that the percentage of leakage detected was substantially less than 0.01%. The filters were tested to breakthrough to obtain their protective life. The "break time" and "protective life time" determined for the NPP-2 filter cells were both acceptable.

Set No. 2

This test, to verify adsorber efficiency, consisted of subjecting six adsorber cells which had undergone rough handling to a high concentration of DMMP, a GB simulant. The cells were required to adsorb a minimum of 200,000 mg-min/m^3 of DMMP with leakage not to exceed 0.01% of the upstream challenge concentration. A value of 200,000 mg-min/m^3 was determined as the maximum challenge concentration that the adsorber might encounter from a GB-saturated airstream passing through the cell at the rated flow for 20 minutes. All six cells successfully passed this test with values exceeding 300,000 mg-min/m^3 (see section 4.1.1.3.2.).

Set No. 3

An actual agent-challenge test with live GB was conducted on the UPA filter system on 8-9 January 1977 in accordance with an approved test plan. Specific test objectives were:

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*Model NPP-2, manufactured by Farr Filter Co., Los Angeles, California

1. Demonstrate that a CAMDS filter system can maintain the established stack emission limit of 3.0×10^{-4} mg/m^3 for GB under the worst-case challenge condition (determined to be 300 mg/m^3).

2. Determine the actual reduction ratio for GB agent challenging a single adsorber bank.

The test results[13] showed:

1. The UPA filter unit is capable of maintaining the established GB stack emission limit of 3.0×10^{-4} mg/m^3 under worst-case challenge conditions.

2. The reduction ratio of a single adsorber bank is smaller than 9×10^{-8}*.

3. The dosage of a single adsorber bank at breakthrough exceeds 1.2×10^5 mg-min/m^3.

Subsequent on-site tests at CAMDS have demonstrated that leakage occurring through installed filters and adsorbers usually takes place between the sealing frame and mounting frame and is invariably caused by poor clamping. All tested cells were visually examined prior to installation. Very few prefilters and HEPA filters, and no adsorber cells, were found to be damaged. All damaged units were rejected for use and returned to their manufacturers.

Several banks failed the applicable leakage tests. In all instances but two, the problem was directly traced to inadequate clamping of a cell or cells to the mounting frame. In the two exceptions, pin holes were discovered in the frames of HEPA filters, and these were believed caused by overclamping considerably beyond simple hand tightness.

*Supply of allocated GB agent was consumed before breakthrough of adsorber bank could be achieved.

8. APPLICATION OF AIR CLEANING CONCEPTS TO DATS

8.1. Introduction

The basic principles of the CAMDS air filter/ventilation system have recently been applied to a new air-cleaning system being developed for DATS (Drill and Agent Transfer System). DATS is intended to serve as a portable unit at remote facilities housing small quantities of unserviceable chemical munitions. Its purpose is to drain and decontaminate the munitions without exceeding chemical-agent emission standards. A detailed description of the DATS filter/ventilation system, designed by CSL, follows.

8.2. Description

DATS is designed to process small groups of unserviceable munitions, one at a time, at a rate of five items per day. The DATS site uses a 666-cfm glovebox and ventilation system (figure 8-1) for this purpose. The latter system includes an air filter housing, primary and emergency blowers, dampers, switches, indicator-light gages, and sampling ports. The air-filter housing contains a pre-filter section, a HEPA filter section, two adsorber sections, and a final HEPA filter section. All key components of the system are shown in figure 8-2.

The emergency blower is provided in case of failure of the primary blower (figure 8-3). Seven dampers are located throughout the system to regulate the airflow as desired (figure 8-4). The operator's console panel (figure 8-5) contains two selector and four pushbutton switches, 13 indicator lights, and six differential pressure (Magnehelic) gages. Additional differential pressure gages are located on the loading chamber and glovebox; the latter also contains a pressure switch/gage (Photohelic). Figure 8-6 depicts the locations of the various sampling ports and inspection plates on the filter housing.

The 666-cfm air-filter system is designed to remove contaminants from the exhaust air of the glovebox and loading chamber, both of which provide containment for chemical agents. Front and rear views of the 666-cfm filter housing are shown in figures 8-7 and 8-8, respectively. Figure 8-9 illustrates the airflow pattern through the housing.

Airflow through the glovebox, normally ranging from 600 to 666 cfm, is maintained by a 5-hp blower (primary or emergency) and is indicated by one of the gages on the control console. The five other gages on the console indicate differential pressure across each filter/adsorber and are monitored for information on filter status.

A list of the major equipment associated with the DATS ventilation system (exclusive of filters and adsorbers) is given in Table VIII-1.

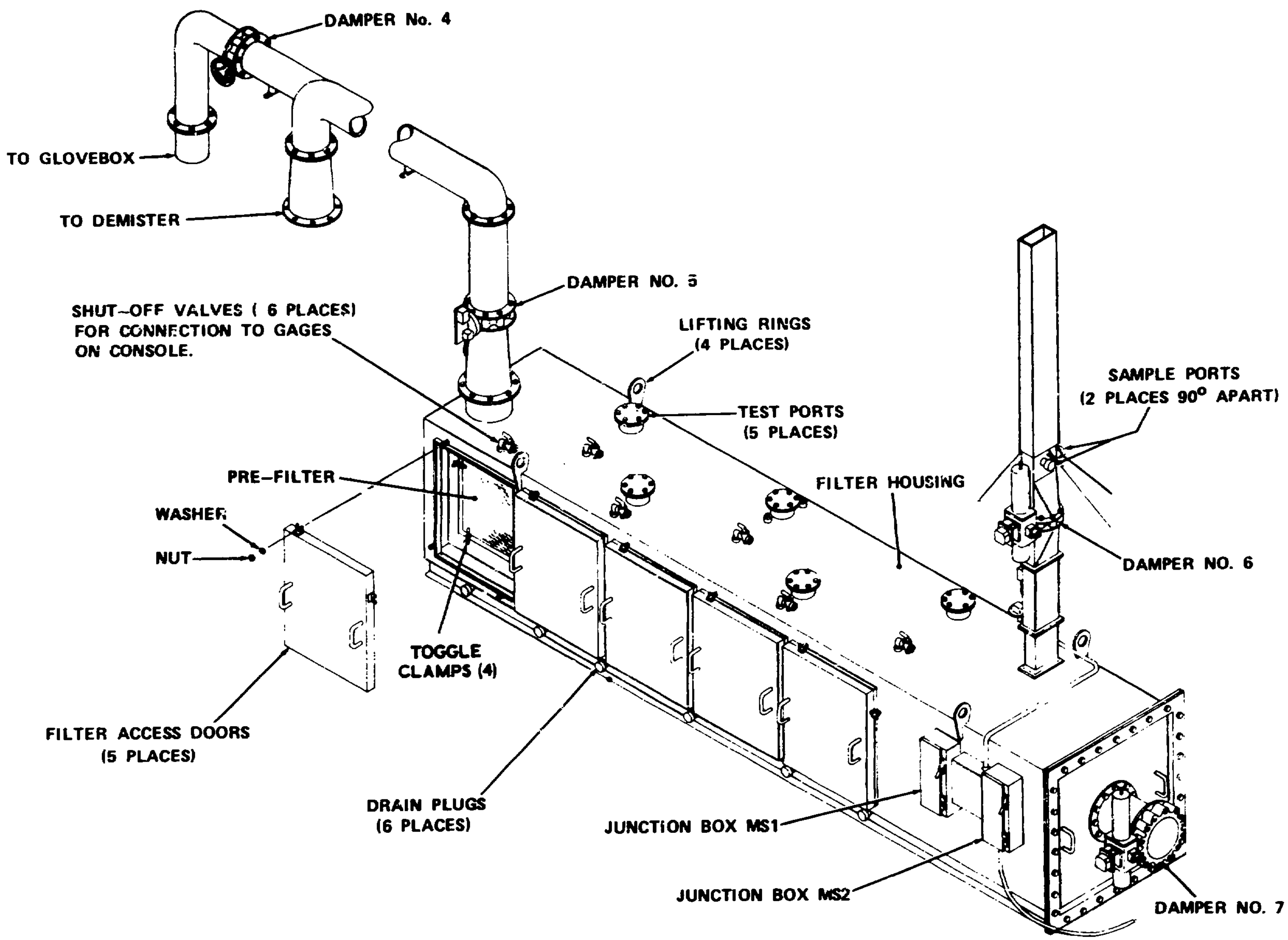


Figure 8-1. 666 Cfm Glovebox Ventilation System For DATS

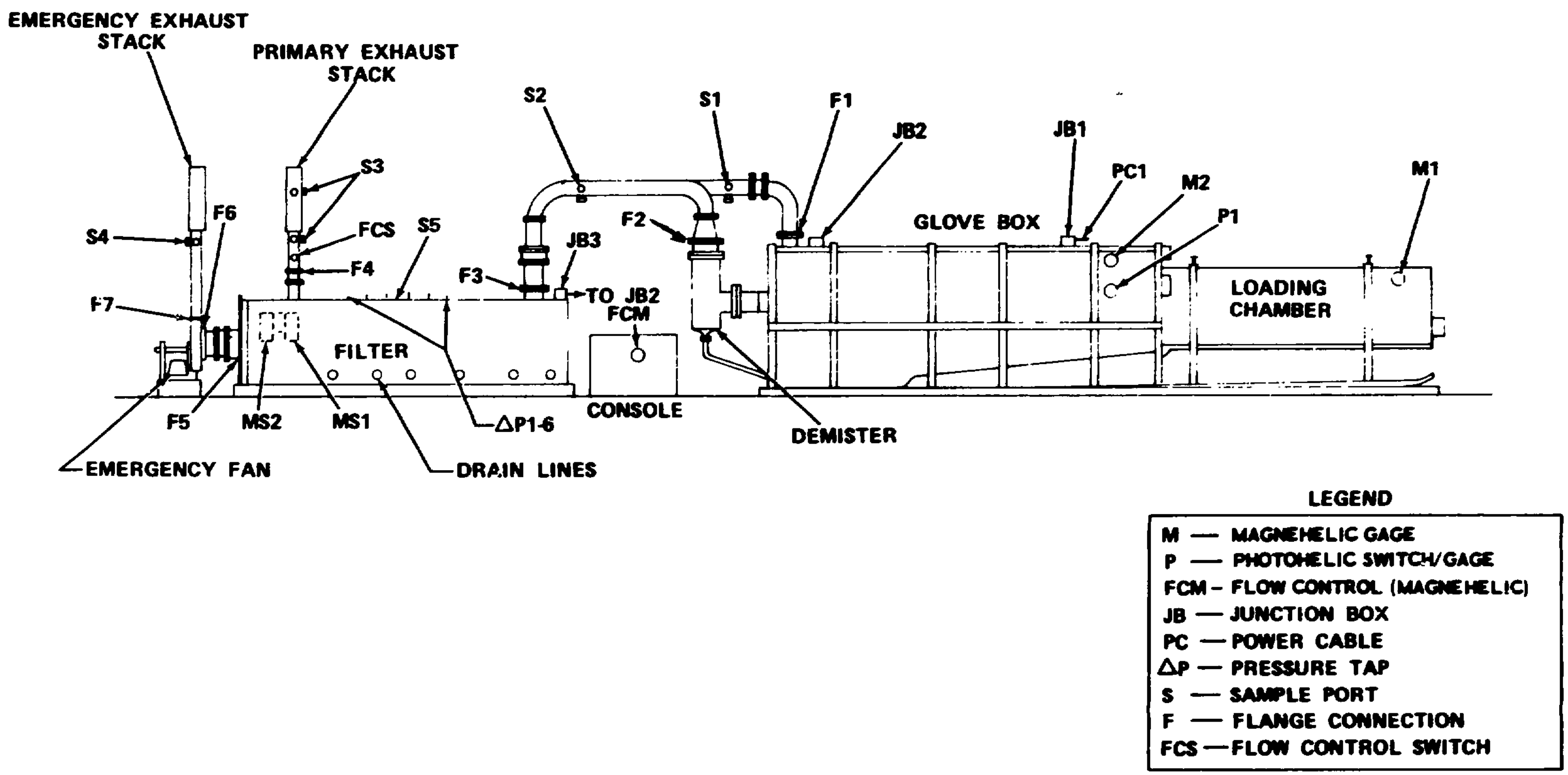


Figure 8-2. Key Components Of DATS And Airflow Measurement Locations

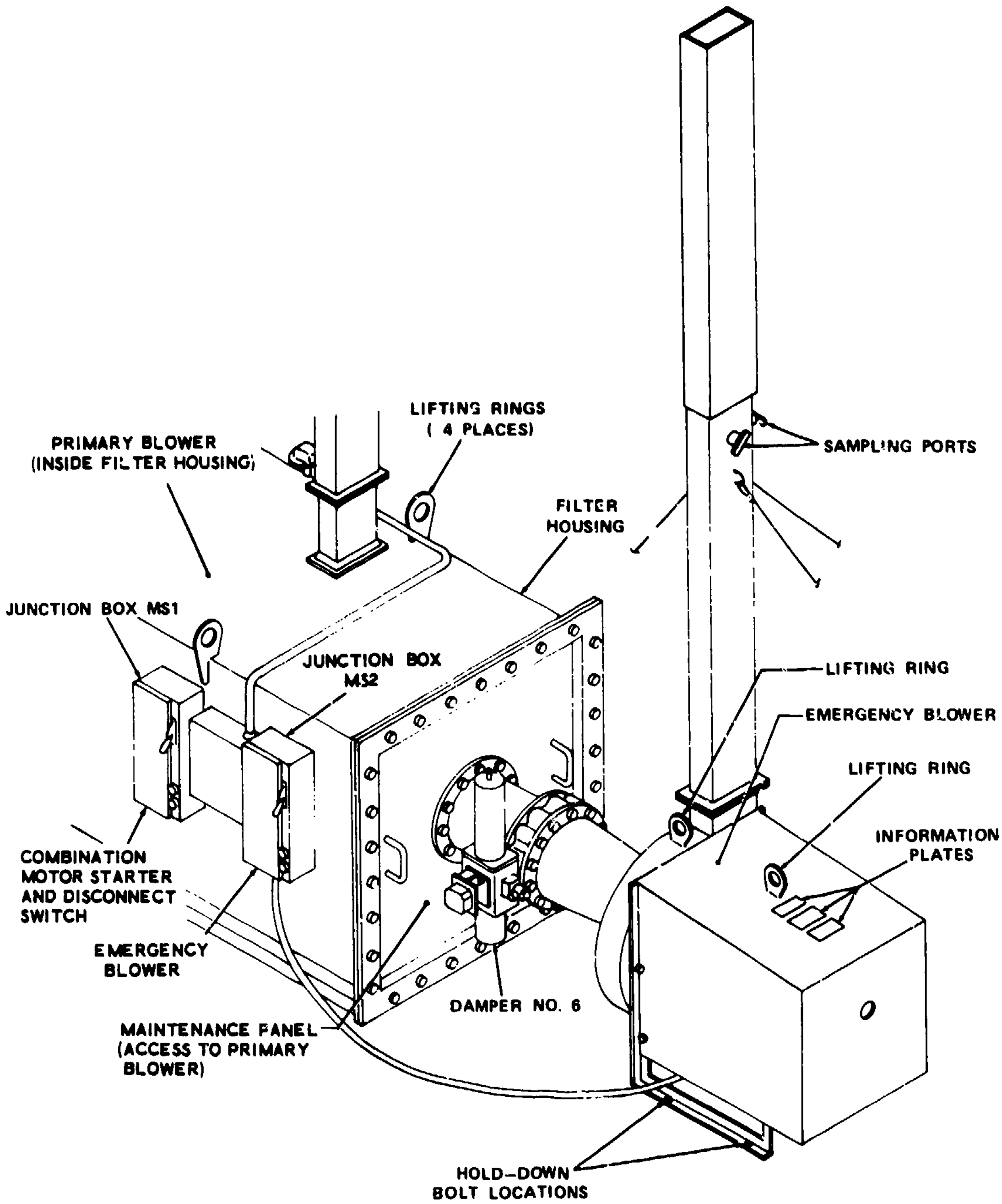


Figure 8-3. Primary And Emergency Blower For DATS

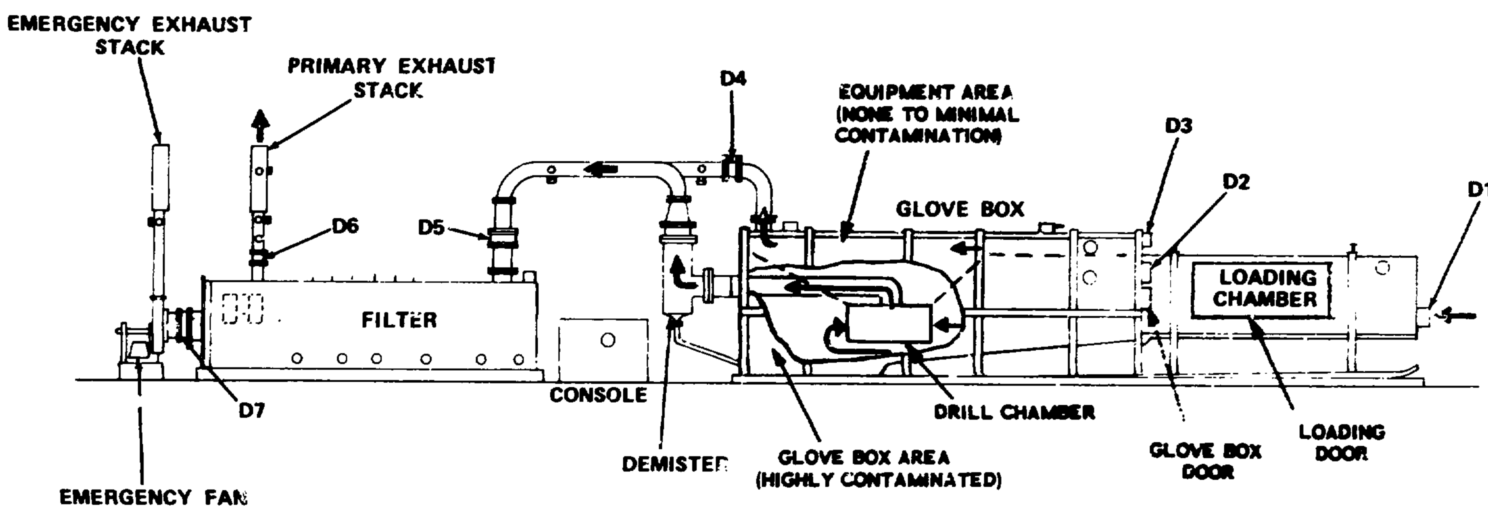


Figure 8-4. Damper Locations And Airflow For DATS

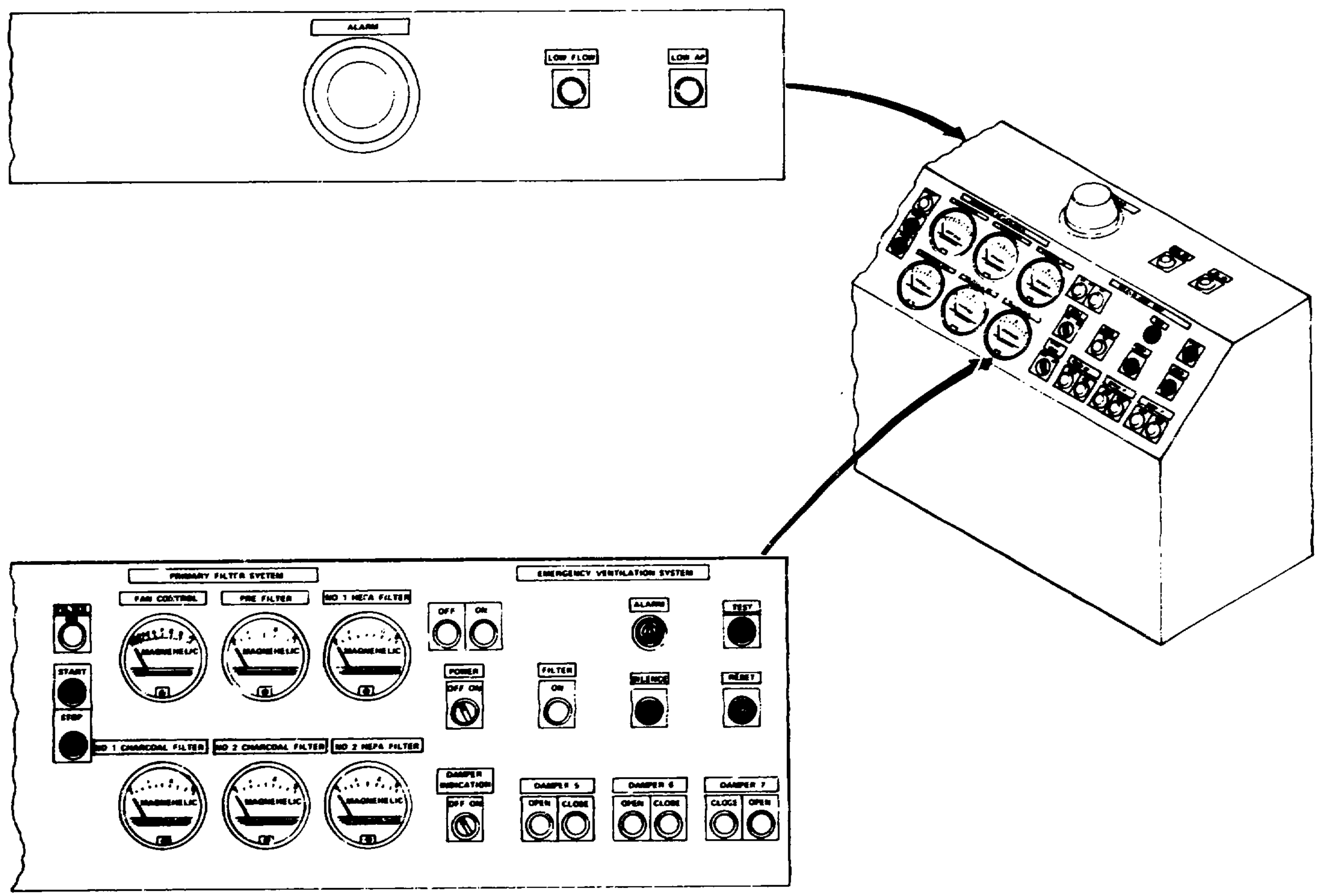


Figure 8-5. Operator's (nsole Panel

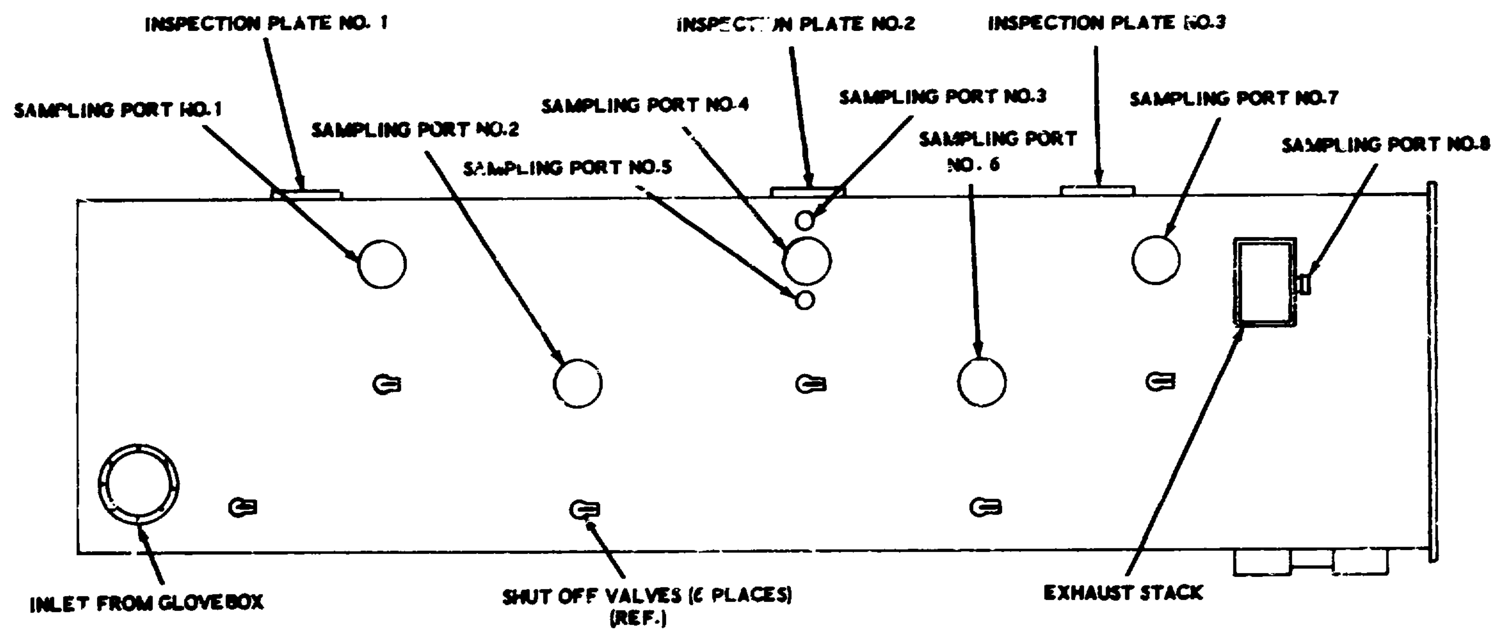


Figure 8-6. Sampling Ports And Inspection Plates On 666 Cfm Filter Housing For DATS

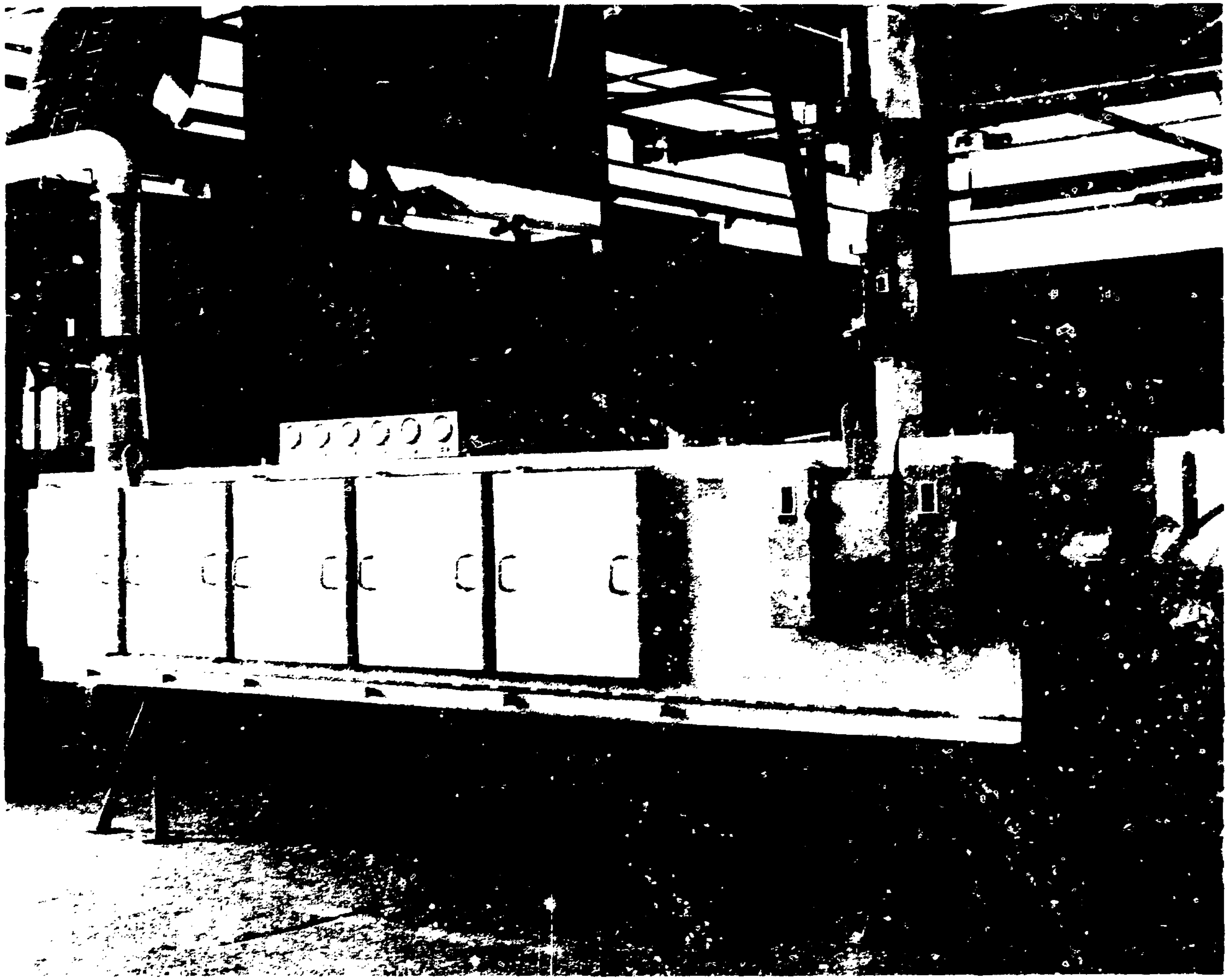


Figure 8-7. Front View Of 666 Cfm Glovebox Ventilation System For DATS

Figure 8-8. Rear View Of 666 Cfm Glovebox Ventilation System For DATS. Location Of Four Removable Inspection Plates Is Typical Arrangement For Type I Filter Systems

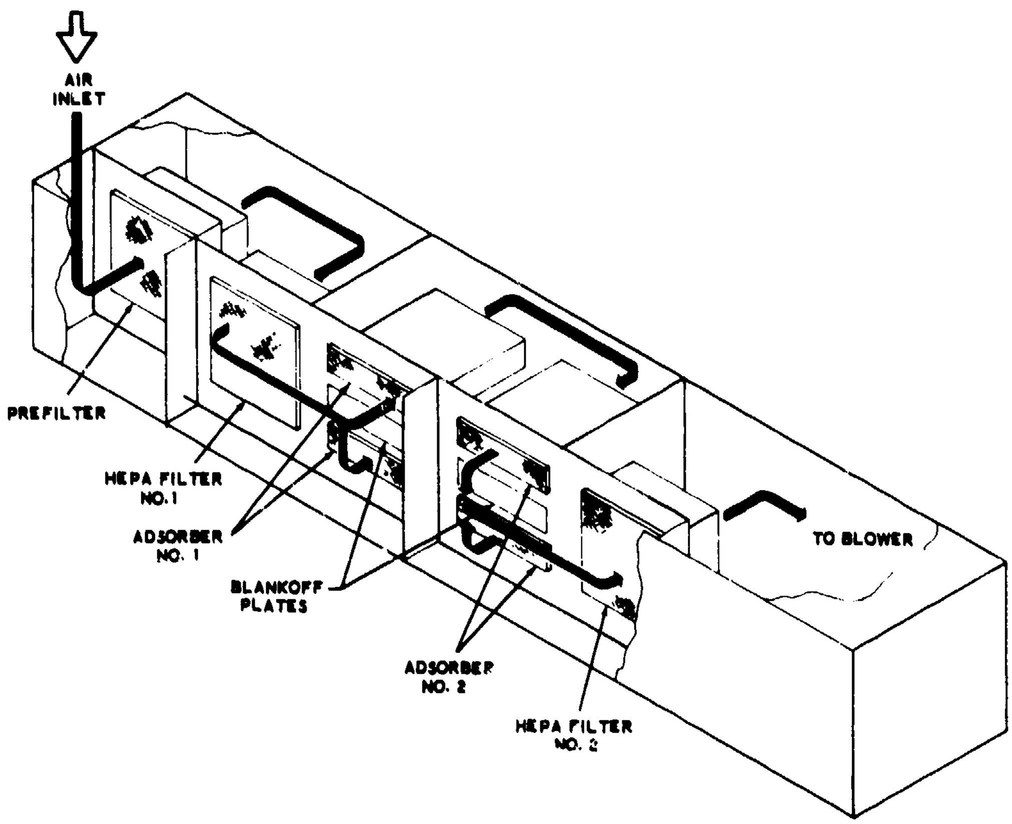


Figure 8-9. Diagram Of Airflow Through DATS Filter Unit

Table VIII-1. Major Equipment For DATS Filter/ Ventilation System

Item No.	Equipment	Description	Location
1	Primary Blower:		See figure 8-3.
	a. Fan	Centrifugal, size 400, 3629 rpm, Model 39759/1-72989, mfd. by Aerovent, Inc.	
	b. Motor	5 hp, 2.6 bhp, 3450 rpm, 230 V, 3 phase, 60 cycle, mfd. by Westinghouse Electric Corp.	
2	Emergency Blower	Same as above	See figure 8-3.
3	Differential Pressure Gage (Magnehelic), 2 ea.	Dwyer Instruments, Inc. Model No. 2000-0-LT, 0-.50, in. wg.	One gage is on load chamber and one is on equipment area of glovebox.
4	Pressure Switch/Gage (Photohelic)	Dwyer Instruments, Inc. Model No. 3000-0-SR-LT, 0-.50 in. wg.	On work area portion of glovebox.
5	Differential Pressure Gage (Magnehelic), 5 ea.	Dwyer Instruments, Inc. Model No. 2003-LT, 0-3 in. wg.	At control console, with tubing routed to pressure taps on each of 5 filter sections.
6	Large Diaphragm Pressure Switch	Dwyer Instruments, Inc. Model No. 1638	On primary exhaust stack.
7	Compact Low Differential Pressure Switch	Dwyer Instruments, Inc. Model No. 1910	At control console, with tubing routed to pressure taps on primary exhaust stack.
8	Differential Pressure Gage (Magnehelic)	Dwyer Instruments, Inc. Model No. 3000	At control console

8.3. Operation

8.3.1. General

Each unserviceable munition to be processed in DATS is brought individually to the loading chamber (which functions as an airlock), where it is placed inside and the load door closed. The munition then is automatically transported into the glovebox through the glovebox door (the glovebox door and loading chamber door are interlocked so that both cannot be opened at the same time). Inside the glovebox, all packaging is removed and the item is transported to the drill chamber section of the glovebox for processing; this consists of drilling, agent draining, and decontamination. The procedure is reversed when the munition is removed.

A demister located between the glovebox and filter removes moisture from the airstream caused by the decontamination and rinsing liquids.

Two airstreams comprise the glovebox ventilation plan. The primary airflow enters the loading chamber through damper D1 (see figure 8-4), flows through the chamber, enters the glovebox through damper D2, flows through the glovebox and drill chamber, and exits through the demister into ductwork leading to the filter systems. A second, smaller airflow enters the equipment area of the glovebox through damper D3, flows through the equipment area into a duct and through damper D4, merging with the main airflow downstream of the demister.

This ventilation system is designed to maintain negative pressure throughout the loading chamber, drill chambers, equipment area, and glovebox so that there is no outward flow. Since the drill chamber is potentially the most contaminated area, it is at a higher negative pressure in order to localize the contamination and prevent its spread to the rest of the glovebox.

Table VIII-2 shows how the air balancing is affected by various airflow conditions within the ventilation system.

8.3.2. Low Flow

Low - or loss of - airflow in the glovebox is sensed by a diaphram-operated differential pressure switch (similar to the Dwyer Instrument Co. switch described in section 4.1.2.12.4). When the airflow drops below 275 cfm,* the pressure switch signals the control

*This value was arbitrarily established by design personnel and may be revised at a later date based on safety and/or in-house test considerations.

Table VIII-2. Ventilation System Balance Conditions For DATS

Item No.(a)	Condition 1 (Basic) Load Door Closed & Glovebox Door Closed(b)	Condition 2 Load Door Open & Glove-box Door Closed (c)	Condition 3 Load Door Closed & Glove-box Door Opened (d)	Condition 4 Emergency Blower On (e)
D1	600 cfm	0	600 cfm	600 cfm
D2	600 cfm	600 cfm	0	600 cfm
D3	66 cfm	66 cfm	66 cfm	66 cfm
D4	66 cfm	66 cfm	66 cfm	66 cfm
D5	666 cfm	666 cfm	666 cfm	666 cfm
D6	666 cfm	666 cfm	666 cfm	0 cfm
D7	0	0	0	666 cfm
S1	66 cfm	66 cfm	66 cfm	66 cfm
S2	666 cfm	666 cfm	666 cfm	666 cfm
S3	666 cfm	666 cfm	666 cfm	0
S4	0	0	0	666 cfm
M1	-.1 in. wg	0	-.1 in. wg.	-.1 in. wg.
M2	-.1 in. wg.	-.1 in. wg.	-.1 in. sg	-.1 in. wg.
P1	-.3 in. wg	-.2 in. wg.	-.3 in. wg.	-.3 in. wg.
FCM	666 cfm	666 cfm	666 cfm	666 cfm

Notes:

(a) Legend:

D - Damper
S - Sampling Port
M - MAGNEHELIC Differential Pressure Gage
P - PHOTOHELIC Pressure Switch/Gage
FCM - MAGNEHELIC Flow Control

(b) Load door and glovebox door are interlocked so that both cannot be opened at same time.

(c) When munition is put in or removed from loading chamber.

(d) When munition is transferred from loading chamber to glovebox.

(e) When primary blower fails to provide sufficient airflow.

console of an alarm condition, actuating both an audible and visual alarm and energizing a control relay, causing the emergency blower to start. A set of holding contacts ensures that the control relay remains energized once the loss of flow occurs, even if momentarily. The emergency-blower starter is controlled through a set of contacts from the control relay and interlocked with damper no. 7, located between the back of the filter and the intake of the emergency blower. Before the emergency blower can start, the damper must be open. A red light on the console indicates when the emergency blower starts.

8.3.3. Low Differential Pressure

Differential pressure gages in the loading chamber and both sections of the glovebox indicate the status of negative pressure in these enclosures. One of these three gages (the one in the contaminated section of the glovebox), in addition to sensing low ΔP, is also capable of signaling this condition to the control console. This capability is not incorporated in the other two gages since they are not involved with contaminated areas. Since low ΔP could occur in the glovebox with the airflow through the system remaining at an acceptable level, the emergency blower does not actuate when the low ΔP alarm occurs; it is a warning alarm only.

8.3.4. Power

Three-phase electrical power for operating the primary and emergency blowers is routed from the generator through two disconnect switch boxes (MS1 and MS2 in figure 8-3) on the filter unit. Single-phase 120-volt power to the console for operating all control functions, solenoid valves, motor starters, etc., is routed directly from the generator to the console.

8.3.5. Emergency Sequence

The emergency blower automatically activates upon loss of airflow through the glovebox. If the flow drops below the preset value on the fan-control gage, damper no. 6 will close and damper no. 7 will open, energizing the motor starter of the emergency blower. The primary blower will stop and cannot be restarted as long as the emergency blower is operating.

8.3.6. Dampers

The operation and purpose of the seven dampers are explained in Table VIII-3. The positions of dampers no. 5, 6, and 7 are monitored on the console. Damper no. 5 must always show OPEN during both primary and emergency blower operation. Damper no. 6 indicates OPEN (green light) and damper no. 7 indicates CLOSED (green light) when the primary blower is operating; both dampers indicate a red light (for CLOSED and OPEN, respectively) when the emergency blower is running.

Table VIII-3. Purpose And Function Of Dampers In DATS Ventilation System

Damper No.	Purpose	Function
1	To create -.1 in. wg in load area under all conditions except when glovebox door is open. To create -.3 in. wg in both loading chamber and glovebox when glovebox door is open.	Normally OPEN. Pneumatically operated. Damper required to have two OPEN positions. OPEN position of damper controlled by pneumatic signal from glovebox door received by air valve (3-way) connected to the damper actuator. Damper has manual stop to prevent damper from fully closing during operations due to unscheduled loss of compressed air. For shutdown manual stop removed. Spring return in pneumatic actuator will close damper and maintain sufficient tension on damper blade to minimize leakage.
2	To create -.2 in. wg in glovebox. Operates when glovebox door is closed. Closes when glovebox door is open since opening for glovebox door has greater cross-sectional area.	Normally OPEN. Mechanically operated to minimize moving parts and fabricated from stainless steel since corrosive atmosphere during some operations probable. Mechanical dampers cannot meet leakage requirements of pneumatic or electric dampers. Since damper internally located extremely low leakage not required.
3	To create .1 in. wg in equipment area.	Noramlly OPEN. Pneumatically operated with only one open position. Pneumatic operator contains spring return. When compressed air supply disconnected, spring return in pneumatic actuator closes damper and maintains sufficient tension on damper blade to minimize leakage.

(continued)

Table VIII-3. Purpose and Function of Dampers in DATS Ventilat ,n System (continued)

Damper No.	Purpose	Function
4	To provide adjustment necessary to balance air flow rates between glovebox (600 cfm) and equipment area (66 cfm)	Normally OPEN. Chain-operated manual damper. Chain mechanism produces sufficient tension on damper blade to minimize leakage when damper is closed.
5	To isolate filter housing from glovebox when filter is not in operation, thus preventing back-flow of contaminated air.	Normally OPEN. Chain-operated manual damper. Chain mechanism produces sufficient tension on damper blade to minimize leakage when damper is closed. Limit switch gives position of damper on console.
6	To seal primary exhaust stack and prevent backflow when emergency blower is in operation.	Normally OPEN. Operated by a pneumatic actuator on signal from a solenoid valve. Signal for solenoid valve comes from control console. Damper 6 will close only if damper 7 has opened. Designed for minimum leakage at several inches wg. Equipped with limit so position of damper can be displayed on console.
7	To seal ductwork between filter housing and emergency blower and prevent backflow through emergency exhaust stack when primary blower is in operation.	Normally CLOSED. Operated by a pneumatic actuator on signal from a solenoid valve. Signal for solenoid valve comes from control console. Designed to minimize leakage at several in. wg. Limit switch gives position of damper on console.

9. LITERATURE CITED

1. Smith, G., et al, Report No. ENCR 30, "Protection of Structures from Chemical, Biological and Radiological (CBR) Contamination," U. S. Army Chemical Corps Engineering Command, June 1959 (Reprinted March 1962).

2. MIL-HDBK-753, "CB Collective Protection of Mobile Vehicles, Vans and Shelters," Dept. of Defense Military Standardization Handbook, 31 August 1971.

3. DARCOM Regulation 385-102, "Safety Regulations for Chemical Agents GB and VX," Dept. of Army Development and Readiness Command Regulation, February 1977.

4. "Industrial Ventilation, A Manual of Recommended Practice," 14th Edition, American Conference of Governmental Industrial Hygienists, 1977.

5. "ASHRAE Handbook of Fundamentals," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., 1972.

6. Jonas, L. A., J. A. Rehrmann, and J. M. Eskow, "Kinetics of Trace Gas Adsorption from Contaminated Air;" reprint from American Chemical Society Symposium Series No. 17, "Removal of Trace Contaminants from the Air," 1975.

7. Burchsted, C.,J.Kahn, and A. Fuller, ERDA Report 76-21, "Nuclear Air Cleaning Handbook," Energy Research & Development Administration, July 1969.

8. ANSI N510, "Standard for Testing of Nuclear Air Cleaning Systems," American National Standards Institute, 1975.

9. ASTM D1056, "Specification for Sponge and Expanded Cellular Rubber Products," American Society for Testing and Materials, 1973.

10. AACC CS-8, "Standard for High Efficiency Gas Phase Adsorber Cells," Institute of Environmental Sciences, July 1972.

11. CSL 611-21, "Test Plan for Building Block (BB) No. 23, Balancing and Testing of the CAMDS Heating and Ventilating System, Test No. CAMDS 23-4," Dugway Proving Grounds, Dugway, Utah, January 1977.

12. AMCA 201, "Fan Application Manual," Air Moving and Conditioning Association, Inc. (Date unknown.)

13. Daughdrill, D., CSL 611-19, "Detailed Test Report - GB Challenge Testing of the CAMDS Unpack Area Filter Unit," Office of Program Manager for Chemical Demilitarization and Installation Restoration, Aberdeen Proving Ground, Md., February 1977.

14. "Guidelines for Air Pollution Source Sampling Site Preparations and Compliance Testing at Army Facilities," U. S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, Md., January 1975.

15. ASHRAE Standard 52-68, "Method of Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter," American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., August 1968.

16. ANSI N509, "Nuclear Power Plant Air-Cleaning Units and Components," American National Standards Institute, 1976.

17. UL-900, "Safety Standard for Air Filter Units," Underwriters' Laboratories, 1971.

18. AACC CS-1, "Standard for HEPA Filters," Institute of Environmental Sciences. (Date unknown.)

19. UL-586, "Safety Standard for High Efficiency Air Filter Units," Underwriters' Laboratories, 1977.

20. MIL-F-51079, "Filter, Medium, Fire Resistant, High Efficiency," Dept. of Defense Military Specification, September 1963.

21. MIL-F-51068, "Filter, Particulate, High Efficiency, Fire Resistant," Dept. of Defense Military Specification, December 1970.

22. ASTM A167, "Specification for Stainless and Heat-Resisting Chromium Nickel Steel Plate, Sheet, and Strip," American Society for Testing and Materials, 1974.

23. ASTM A240, "Specification for Corrosion-Resisting Chromium and Chromium-Nickel Steel Plate, Sheet, and Strip," American Society for Testing and Materials, 1975.

24. ASTM A176, "Specification for Stainless and Heat-Resisting Chromium Steel Plate, Sheet, and Strip," American Society for Testing and Materials, 1975.

25. MIL-C-13724, "ASC, Impregnated, Activated Charcoal," Dept. of Defense Military Specification, September 1972.

26. ASTM D2652, "Definitions of Terms Relating to Activated Carbon," American Society for Testing and Materials, 1976.

27. ASTM D2862, "Particle Size Distribution of Granular Activated Carbon," American Society for Testing and Materials, 1970.

28. ASTM E323, "Perforated Plate Sieves for Testing Purposes," American Society for Testing and Materials, 1970.

29. ASTM D1330, "Specification for Sheet Rubber Gaskets," American Society for Testing and Materials, 1972.

30. ANSI B46.1, "Suface Texture," American National Standard Institute, 1971

31. TM 3-6665-225-12, "Alarm, Chemical Agent, Automatic: Portable," Dept. of Army Technical Manual, August 1975.

32. DARCOM Regulation 385-31, "Safety Regulations for Chemical Agents H, HD and HT," Dept. of Army Development and Readiness Command Regulation, September 1975.

33. CSL 100-26, "Medical Surveillance of Personnel Potentially Exposed to Cholinesterase Inhibiting Substances (CIS)," Letter AMCMM-O, Commanding General, Army Materiel Command, to Project Manager, Chemical Demilitarization and Installation Restoration, Aberdeen Proving Ground, Md., 11 December 1975.

34. DA Pamphlet 385-3, "Protective Clothing Equipment," Dept. of Army, 1968.

35. TM 750-5-15, "Chemical Weapons and Defense Equipment," Dept. of Army Technical Manual, April 1969.

36. TM 10-277, "Protective Clothing Chemical Operations," Dept. of Army Technical Manual, July 1967.

37. TM 3-4240-258-14, "Mask, CBR; Field, M17A1 and Accessories," Dept. of Army Technical Manual, March 1968.

38. TM 3-4240-240-14, "Mask, Chemical-Biological, Special Purpose, M9A1; Mask, Chemical-Biological, Special Purpose, M9; and Accessories," Dept. of the Army Technical Manual, 26 October 1970.

39. FM 3-21, "Chemical-Biological Accident Contamination Control," Dept. of Army Field Manual, August 1972.

40. MIL-STD-282, "Filter Units Performance Test Methods," Dept. of Defense Military Standard, May 1956.

41. FM 3-9, "Military Chemistry," Dept. of Army Field Manual, October 1975.

42. CSL 611-22, "Test Plan for Building Block (BB) No. 23, Acceptance Test of CAMDS Air Filter Systems, Test No. CAMDS 23-3," Demilitarization/Disposal Office, Edgewood Arsenal, Aberdeen Proving Ground, Md., 20 September 1976.

43. CSL 611-20 (IM323-01-20), "Performance Test and Element Replacement Manual for Air Filter Systems," CAMDS Directorate, Tooele Army Depot, Utah, May 1977.

44. Smith, G., Report No. ARCSL-SP-77004 (EM-SP-77005), "Performance Evaluation of Gas Filters," April 1978 (Planned).

45. "TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977," American Conference of Governmental Industrial Hygienists, 1977.

10. GLOSSARY OF TERMS

10.1. Acronyms and Abbreviations

A - Area

AACC - American Association for Contamination Control (now Institute of Environmental Sciences)

ACGIH - American Conference of Governmental Industrial Hygienists

ADS - Agent Destruction System, a unit of CAMDS

AEC - Atomic Energy Commission (see also ERDA)

AEHA - Army Environmental Hygiene Agency

AFI - Air Filter Institute

AMCA - Air Moving and Conditioning Association

ANSI - American National Standards Institute

ARI - Air-Conditioning and Refrigeration Institute

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

ASME - American Society of Mechanical Engineers

ASTM - American Society for Testing and Materials

AWS - American Welding Society

BET - Brunauer, Emmett, and Teller; test for surface area of adsorbents

bhp - brake horsepower

BIF - Bulk Item Facility, a unit of CAMDS

CAMDS - Chemical Agent Munitions Disposal System, located at Tooele Army Depot, Tooele, Utah

CBR - Chemical/Biological/Radiological

cfm - cubic feet per minute, ft^3/min.

cm - centimeter

CSL - Chemical Systems Laboratory, located at Aberdeen Proving Ground, Md.

DA - Department of the Army

DATS - Drill and Agent Transfer System, another demilitarization system for chemical munitions

d - density

db - decibels, a measure of noise level

decon - abbreviated term for "decontamination"

demil - abbreviated term for "demilitarization"

DFS - Deactivation Furnace System, a unit of CAMDS

dia. - diameter

DMMP - dimethylmethylphosphonate, an agent simulant used to challenge filters

DOD - Department of Defense

DOP - dioctylphthalate, a chemical for generating a liquid aerosol for testing

DPE - Demilitarization Protective Ensemble, a disposable protective clothing outfit for wear by workers in critical chemical demilization operations

ECC - Explosive Containment Cubicle, a unit of CAMDS

ERDA - Energy Research and Development Administration (formerly Atomic Energy Commission, now U.S. Department of Energy)

ETS - Explosive Treatment System, a unit of CAMDS

F_h - hood entry loss factor

fpm - feet per minute, ft/min.

GB - a nerve gas used as a fill in chemical agent munitions

g - gram

in. wg - inches water gage, a measure of pressure

H & V - heating and ventilating

h_e - entry loss; loss in pressure caused by air flowing into a duct or hood.

HEPA - high efficiency particulate air (filter)

hp - horsepower

HTH - High Test Hypochlorite, a decontaminating agent

Hz - Herz (cycles per second), a measure of frequency

in. - inch

kg - kilogram

LEL - Lower Explosive Limit

LEV - Limiting Exposure Value

m - meter

mg/m^3 - milligrams per cubit meter

μm - micrometer (approx. 4.0 x 10^{-5} in.),a measure of particle size; replaces term "micron" in ANSI system of measure.

$\frac{\text{mg-min}}{\text{m}^3}$ - milligram-minutes per cubic meter, a measure of concentration.

min. - minute

MPF - Metal Parts Furnace, a unit of CAMDS

NaOH - sodium hydroxide, a decontaminating agent

NEMA - National Electrical Manufacturers Association

NFPA - National Fire Protection Association

nm - nanometer (10^{-9} meter)

OSHA - Occupational Safety and Health Administration, an agency of U.S. Department of Labor

ΔP - pressure drop or differential pressure, in. wg.

PDF	-	Projectile Disassembly Facility, a unit of CAMDS
PDS	-	Personal Decontamination Station, a unit of CAMDS
PM/CDIR	-	Project Manager for Chemical Demilitarization and Installation Restoration, located at Aberdeen Proving Ground, Md.
ppb	-	parts per billion
PPD	-	Projectile Pull and Drain Machine, a unit of CAMDS
ppm	-	parts per million
PSC	-	Personnel Support Complex, a unit of CAMDS
PSU	-	Permanent Single Unit, a type of adsorber
PVC	-	polyvinyl chloride, a plastic material
Q	-	volumetric flowrate of air, cfm
RH	-	relative humidity
rpm	-	revolutions per minute
sec	-	second
SMACNA	-	Sheet Metal and Air-Conditioning Contractors National Association
SP	-	static pressure, in. wg
SOP	-	standing operating procedure
STB	-	Super Tropical Bleach, a decontaminating agent
UL	-	Underwriters' Laboratories
UPA	-	Unpack Area, a unit of CAMDS
V	-	velocity, fpm
VP	-	velocity pressure, in. wg.
VX	-	a nerve gas used as a fill in chemical agent munitions

10.2. Terms and Phrases

<u>acceptance test</u>. Test made upon completion of fabrication, installation, repair, or modification of a system, unit, component or part to verify to the user or owner that the item meets specified requirements.

<u>adsorbent</u>. Material - e.g., carbon, silica gel - for removing gases or vapors from air by means of physical condensation and retention of molecules on a solid surface; often impregnated with chemicals to increase its ability to remove certain low molecular-weight gases.

<u>adsorber cell</u>. Modular replaceable element filled with an adsorbent. Term is used interchangeably with gas filter, carbon filter, charcoal filter, gas adsorber, adsorber tray, etc.

<u>aerosol</u>. Dispersion of very small particles and/or droplets suspended in air; diameter of particles may vary from 100 microns down to 0.01 micron.

<u>bag-in, bag-out</u>. Method of introducing and removing items from a contaminated enclosure (designated Type I filter housing) that prevents the spread of contamination or opening of the contaminated space to the atmosphere through the use of plastic bagging material.

<u>bag-out</u>. Modified version of bag-in, bag-out procedure in which plastic bag is not installed beforehand in housing.

<u>blankoff plate</u>. Plate used in a modular bank of HEPA filters or adsorber cells to block off unneeded capacity.

<u>blast gate</u>. Sliding damper

<u>breakthrough</u>. Penetration of chemical agent through an adsorber cell as determined by a sensitive detector.

<u>case, casing</u>. Frame or cell enclosing a modular filter element or adsorber cell; usually constructed of metal.

<u>changeout</u>. Procedure used for changing damaged or spent filters or adsorber cells.

clean-air system. Air-cleaning system designed to maintain a defined level of air cleanliness, usually in terms of a permissible number of particles in a given size range per unit volume within an enclosed working area.

coating. Paint or other protective surface treatment applied by brushing, spraying, or dipping (does not include metallic plating).

contaminated exhaust system. Air-cleaning system designed to remove harmful or potentially harmful particulates, aerosols, or gases from the air exhausted from a contained space.

contaminated (dirty) work area. Any work area in which there is a likelihood of personnel, equipment, or the facility itself being contaminated.

contamination. Presence of unwanted hazardous material in the air, in process fluids, or on surfaces. Assumed in this handbook to be a chemical agent.

damper. Movable plate or valve located in the ductwork of a ventilation system for controlling the airflow or draft; may be operated manually, pneumatically, hydraulically, etc.

decontamination. Removal and/or destruction of unwanted hazardous substances from personnel, rooms, building surfaces, equipment, etc., by chemical or physical means.

demilitarization. Process of rendering military hardware unusable for its originally intended purpose. In this handbook the term generally refers to the detoxification of chemical agents and associated chemical munitions.

demister. Generic term for devices to remove entrained moisture from air.

differential pressure. Difference in air pressure between two areas separated by some type of barrier; same as ΔP.

differential pressure switch. Device which uses differential air pressure to actuate an electric switch at a preset actuation point (see Photohelic).

DOP aerosol. Dispersion of dioctylphthalate (DOP) liquid droplets in air; constitutes accepted test method for determining overall efficiency of HEPA filters.

dry-type filter. Filter having a medium that is not coated with an oil or adhesive to improve its retention of large particles.

element. As used in this handbook, a generic term for prefilter, HEPA filter, or adsorber.

entry loss. Loss in pressure caused by air flowing into a duct or hood.

extended-medium filter. Filter having a pleated medium or other shape to increase its surface area relative to the frontal area of the filter.

filter. Device having a porous or fibrous medium for removing suspended particles from air or gas passing through the medium; as used in this handbook, the term applies only to the prefilter and HEPA filter, not the adsorber.

filter bank. Parallel arrangement of filters on a common mounting frame enclosed within a single housing.

final filter. Last bank of filters in a set of filter banks arranged in series.

Freon-12. Fluorocarbon compound dispersed as a gas in the air; used to test the quality of fabrication and installation of adsorbers.

gas chromatograph. Analytical instrument used for quantitative analysis of extremely small quantities of organic compounds; its operation is based upon the absorption and partitioning of a gaseous phase within a column of granular material.

glovebox. Sealed enclosure in which handling of items is conducted through rubber gloves sealed to ports in the walls of the enclosure. The operator places his hands and forearms in the gloves from the room side of the box so that he is physically separated from the glovebox environment and is able to manipulate items inside the box with relative freedom while viewing the operation through a window.

HEPA filter. Disposable, extended-pleated, dry-type filter with (1) a rigid casing enclosing the full depth of the pleats, (2) a minimum particle removal efficiency of 99.97% for thermally generated monodispersed DOP smoke particles with a diameter of 0.3 μm, (3) a maximum pressure drop of 1.0 in. wg when clean and operated at its rated airflow capacity, and (4) maximum superficial airflow velocity of 5 fpm through its medium when operated at rated capacity.

hood. Shaped inlet designed to capture contaminated air and conduct it into an exhaust duct system.

hot. Highly contaminated.

hot line. Limit established for safety precautions beyond which no contaminated items or persons are allowed to pass.

inches of water. A unit of pressure (1 in. wg = 0.036 psi).

latent heat. Heat that does not affect the temperature but changes the state of a substance when added to or subtracted from it.

leakage. Unintentional passage of contaminated material around or through an installed filter or adsorber, or through a pressure barrier.

local exhaust ventilation. Ventilation system for removing any contaminated materials likely to be generated from a localized "hot" operation.

Lower Explosive Limit. Lower limit of flammability or explosibility of a gas or vapor at ordinary ambient temperatures expressed in percent of the gas or vapor in air by volume. Assumed constant for temperatures up to 250°F; above this temperature it should be decreased by a factor of 0.7 since explosibility increases with higher temperatures.

Magnehelic. Tradename of Dwyer Instruments, Inc. for its line of differential pressure gages.

medium (plural, media). Filtering material in a filter.

mesh. Number of openings in wire cloth per lineal inch.

mounting frame. Structure to which a filter unit is clamped and sealed.

nonregulated area. Work area in which munitions or materials certified as agent-free are routinely handled with minimal need for chemical protection.

negative pressure. Air pressure within a space below atmospheric pressure.

neoprene. Synthetic rubber material.

open-face filter. Filter with no restrictions over the ends or faces of the unit, as opposed to the enclosed filter having reduced-size end connections.

particle, particulate. Minute piece of solid matter having measurable dimensions.

penetration. Measure of the quantity of a test agent that leaks through or around an air-cleaning device when the device is tested with an agent of known characteristics under specified conditions; penetration is expressed as a percentage of the challenge gas or aerosol concentration in the space upstream of the air-cleaning device.

Photohelic. Tradename of Dwyer Instruments, Inc. for a pressure switch combined with a Magnehelic pressure gage.

positive pressure. Air pressure within a space above atmospheric pressure.

pressure drop. Same as differential pressure.

prefilter. Filter unit installed upstream or ahead of another filter unit (usually a HEPA filter) to protect the second unit from high dust concentrations or other environmental conditions. The prefilter usually has a lower efficiency for the finest particles present in the aerosol than the filter it protects (see roughing filter).

PSU adsorber. Same as stationary adsorber.

redundancy. Addition of an independent back-up unit or parallel system which is capable of achieving the objectives of the basic system and which is on-line (series) or can be brought on-line (parallel) in the event of failure to the basic system.

regulated area. Area in which critical chemical-agent operations are performed and which could become accidentally contaminated to pose a hazard. Personnel in such areas must be equipped with protective clothing and equipment.

residence time. Calculated time that a volume of contaminant or test agent theoretically remains in contact with an adsorbent, based on the active volume of adsorbent and the air or gas velocity through the adsorber bed.

rotameter. Instrument for measuring flow rates of air and liquids.

roughing filter. Prefilter with high efficiency for large particles and fibers but low efficiency for small particles; usually of the panel type.

scrubber. Device in which the gas stream is brought into contact with a liquid so that undesirable components in the gas stream are removed by reacting with or dissolving in the liquid.

sensible heat. Heat that changes the temperature of a substance when added to or subtracted from it.

separators. Corrugated foil or asbestos board used to separate and strengthen the folds of a pleated filter medium and to provide air channels between them.

stationary adsorber. Gasketless adsorber permanently installed in a system and which can be emptied of and refilled with adsorbent without removal from the system; also known as PSU adsorber, used in type III filter housing.

surveillance test. Test made periodically to establish the current condition of a system or component.

type I housing. Filter housing designed to accommodate bag-in, bag-out or bag-out procedure for removing filters and adsorbers.

type II housing. See walk-in housing.

type III housing. Walk-in filter housing designed to accommodate replaceable filters and stationary adsorbers.

uncontaminated (clean) work area. Any work area in which there is virtually complete assurance that there is no contamination.

upset. Accident, malfunction, or transient condition of irregularity occurring in air-cleaning system.

walk-in housing. Contaminated enclosure (designated type II housing) from which filters and adsorbers are removed by personnel in protective clothing walking inside the unit.

Appendix A

PROPOSED MAXIMUM ALLOWABLE LIMITS FOR EMISSIONS OF GB, VX, AND MUSTARD FOR CHEMICAL DEMILITARIZATION

Note: These limits have already been approved by the Surgeon General for the CAMDS facility only; they remain proposed, however, for all other applications.

Table A-1. Chemical Demilitarization Work Area Limits for Unmasked Workers (Healthy Adults Medically Evaluated and Cleared for Duty)

Agent	Maximum Allowable Concentration* (mg/m^3)	Duration
GB	0.001	Averaged over any 1-hour period.
	0.0003	Averaged over any 8-hour period.
	0.0001	8-hr/day for an indefinite period; averaged over any 10 consecutive work periods.
VX	0.00005	Averaged over any 1-hour period.
	0.00002	Averaged over any 8-hour period.
	0.00001	8-hr/day for an indefinite period; averaged over not more than 5 consecutive work periods.
Mustard	0.4	Ceiling, i.e., must not be exceeded for any period.
	0.3	Averaged over any 6-minute period (emergency situation).
	0.01	Averaged over any 3-hour period.
	0.005	Averaged over any 8-hour period.
	0.003	8-hr/day for an indefinite period; averaged over not more than 5 consecutive work periods.

*Without eye protection.

Table A-2. Advisory Stack Emission Concentration Limits For Chemical Demilitarization Operations

Agent	Maximum Allowable Concentration (mg/m^3)	Duration
GB	0.0003	Averaged over any 1-hour period
VX	0.00003	Averaged over any 1-hour period
Mustard	0.03	Averaged over any 1-hour period

Table A-3. Ambient Air Quality Limits and Site Perimeter Limits for Chemical Agents (General Population In An Uncontrolled Environment)

Agent	Maximum Allowable Concentration (mg/m^3)	Duration
GB	0.0001	Averaged over any 1-hour period.
	0.000003 *	Averaged over any 72-hour period. (Based on allowable 24-hour exposure dosage of 0.005 $\frac{mg\text{-}min.}{m3}$)
VX	0.0001	Averaged over any 1-hour period.
	0.0000003*	Averaged over any 72-hour period. (Based on allowable 24-hour exposure dosage of 0.005 $\frac{mg\text{-}min.}{m3}$)
Mustard	0.01	Ceiling; must not be exceeded for any period.
	0.00033	Averaged over any 3-hour period.
	0.00017	Averaged over any 8-hour period.
	0.0001*	Averaged over any 72-hour period.

*These values also apply to all site perimeters.

Appendix B

SPECIFICATION FOR CAMDS AIR CLEANING SYSTEM

This appendix presents a compilation of the requirements pertaining to the air cleaning system now installed at CAMDS, Tooele Army Depot, Tooele, Utah. This information is intended to serve as a basis for defining the requirements of other similar air cleaning systems.

1. General

a. Each air filter system for CAMDS shall draw air at the specified volume flow from its associated ventilation system and pass the air through a series of filters in the following sequence: prefilter, HEPA filter, adsorber, second adsorber, and second HEPA filter. The filter system shall include an air-inlet flange coupling for connection to the ventilation ductwork and a blower unit.

b. Each air filter system shall be designed to permit operation outdoors at an altitude of 5,000 ft. above sea level and over a temperature range of -10°F to 110°F.

c. The contractor's filter system design shall be capable of providing a minimum negative pressure of 1.0 in. wg at the filter inlet for the ventilation system ductwork. The ventilation system ductwork is the responsibility of the Government and is not a part of these requirements.

d. With a maximum negative pressure of 1.0 in. wg at the filter inlet, each air filter system shall (1) maintain the specified volume airflow (plus 0 minus 20%) when the filter system's resistance is increased by 100% over its initial value, and (2) maintain the specified volume airflow (plus 0 minus 30%) when the filter system's resistance is increased by 125% over its initial value. If flow-control systems are required to maintain the specified volume flow, such flow-control systems shall use the most efficient design of either controllable pitch fans or fixed-pitched fans with variable-inlet vanes or outlet dampers to avoid wasting electrical power. The air-filter system shall be designed to provide a 1×10^4 reduction in the concentration of gaseous contaminants through each bank of adsorbers.

e. Each complete filter system shall be mounted on a skid. The skid shall be made of a suitable structural steel and painted in accordance with paragraph 1.g.

f. The design of this equipment shall comply with the Occupational Safety and Health Act (OSHA) of 1970. Inasmuch as DOD regulations governing acceptable sound (noise) levels are more restrictive than those of OSHA, the steady-state noise level shall not exceed 85 decibels (db) on scale "A" of a standard sound-level meter at a distance of 20 feet in any direction from the filter system.

g. All structural carbon steel surfaces shall be painted. The surfaces shall be prepared in accordance with MIL-STD-171[1*] and both prime and top coats shall be applied in strict accordance with the paint manufacturer's directions. Paint recommended for use is Rowe Epoloid paint** or an equivalent epoxy paint.

h. The contractor shall furnish one complete set of test equipment required to perform the DOP and freon leak test on installed HEPA filters and adsorbers as indicated in paragraphs 4.b and 5.b, respectively.

2. Filter Housing

a. The filter housing shall provide a complete airtight enclosure from air inlet to air outlet. All necessary framing and support equipment for the filters and adsorbers shall be furnished as part of the housing by the contractor. The contractor shall also furnish all internal galleries, ladders, access doors, hatches, etc., required for the inspection, servicing and/or removal of the equipment housed therein. The side on which the access doors are to be located is given below:

Air Capacity Of Filter System (cfm)	No. of Access Doors	Side for Door Location (Facing The Air Inlet)
333	1	Right side
8,000	1	Right side
2,000	2	Left side
3,000	2	1 each on right side & left side
4,000	1	Right side
6,000	2	1 each on right side & left side
15,000	2	1 each on right side & left side

*See references listed at end of this appendix.
**Product of Rowe Products, Inc., Niagara Falls, New York.

b. The filter housing shall be constructed of carbon steel, except for adsorber mounting frames which shall be constructed of type 316 or 316L stainless steel.

c. The intake transition piece shall be designed to join with ventilation ducts of the following sizes:

Air Capacity Of Filter System (cfm)	Duct Size (in. ID)
333	12
1,000	12
2,000	16
3,000	20
4,000	22
6,000	28
8,000	28
15,000	44

d. Two sampling ports, located between the two adsorber banks, shall be required for each filter housing. In order to obtain a reliable sample, turbulent flow shall be required upstream of the area where the sampling probes shall be located. If turbulent flow is not present, a suitable baffle shall be installed.

e. All sharp corners, welds, weld spatter and projections inside the housing shall be ground smooth to such an extent that operators' clothing shall not be torn if rubbed against any interior surface.

f. All welded joints within the housing shall be 100% welded prior to painting. All welding shall be in accordancd with the applicable specifications listed in paragraph 9.

g. The filter housing shall be suitably reinforced and designed to withstand both a positive and negative differential pressure of at least 24 in. wg with no visible damage or permanent deformation.

h. All structural reinforcing shall be external to the housing to facilitate decontamination. Access doors shall give complete accessibility to all components for servicing. All doors shall be airtight at normal operating pressure.

i. Each housing section shall be equipped with a one-inch diameter, threaded half-coupling, floor-drain connection.

j. Instrumentation shall be furnished for measuring the differential pressure across each filter bank. This instrumentation shall be sized and located so as to be easily readable by operating

personnel; in addition, it shall have a capability of being remotely located if necessary.

k. All housings with an airflow capacity of 3,000 cfm or larger shall be provided with internal lights between each bank of components for visual inspection, in-place testing, and installation and removal of components. The light fixtures shall be of the vapor-tight type, sealed against leakage, adequate for the pressure encountered, and replaceable from outside the housing.

l. The same basic housing shall be used for the 3,000, 4,000, and 6,000-cfm capacity filter systems. Regardless of the rated capacity, all positions for the prefilters and first bank of HEPA filters shall have filter units installed. Positions not required in the 3,000 and 4,000-cfm capacity systems for the adsorbers and second bank of HEPA filters shall remain unfilled and be blocked off with blank plates; the fans shall be sized accordingly for the required flow rates.

m. The housing shall be tested at the contractor's plant for structural rigidity and leaks. All openings in the housing shall be sealed; doors shall be sealed only by their normal latching devices. The housing shall be alternately subjected to a positive and negative differential pressure of at least 24 in. wg, holding the pressure for at least 10 minutes at each condition. The housing shall show no damage or permanent deformation. Following the pressure cycling, a vacuum source shall be connected to the housing through an integrating wet-type flowmeter. A negative pressure of six in. wg $\pm$ 10% shall be maintained for at least 8 hours. Maximum leakage shall not exceed 0.01% of the rated airflow.

3. Prefilters

a. The prefilters shall be rated at 1,000 cfm and be classified as dry, disposable Group III type, with all frames and separators constructed of steel, as defined in ARI Standard 680.[2]

b. The prefilter assembly shall be rated Class I in accordance with UL Standard 900.[3]

c. The prefilters shall have an 80% minimum efficiency at rated flow when tested in accordance with ASHRAE Standard 52-68.[4]

d. The prefilters shall withstand an airflow producing a pressure drop across the filter of at least 5 in. wg for at least 15 minutes without visible damage or loss in filtration efficiency.

4. HEPA Filters

a. The HEPA filters shall be rated at 1,000 cfm and be classified as Type B or Type C, Grade 1, with all frames and separators constructed of steel, as defined in AACC Standard CS-1.*[5]

b. After installation, each HEPA filter and its mounting assembly shall show no leaks when tested in accordance with paragraph 4 of AACC Standard CS-1.

5. Adsorbers

a. The adsorber shall be a Class A, type II tray-type cell in accordance with AACC Standard CS-8[6] except as modified in paragraph 5.b.

b. The following procedure in regard to filling-method qualification testing shall be substituted for paragraph 7.4.2 of AACC CS-8. Six adsorber cells shall be selected at random, filled with an adsorbent of the specified mesh size and hardness by the proposed filling method, mounted on a rough-handling machine with sharp cut-off cams oriented such that the filling port is at the top, and vibrated for 10 minutes at a frequency of 200 cycles per minute at an amplitude of 0.75 in. It shall be permissable to provide external restraints on the retaining screens while the adsorber cells are being vibrated. After rough handling, the filling port shall be opened and the level of adsorbent in the cell examined; the level shall have dropped no more than one-half of the baffle or margin width perpendicular to the adsorbent surface. The six adsorber cells shall then be removed in the same orientation taking care not to disturb the granules of adsorbent and leak tested with freon in accordance with para 7.5.1 of AACC CS-8, except that the cells shall be oriented with filling ports up for the qualification leak test. A minimum of five cells shall show no leakage. Airflow resistance shall not increase by more than 20% as a result of this test.

c. In addition to the requirements listed above from AACC Standard CS-8, the following additional requirements shall be met: Each regular production lot of adsorbers shall be sampled in accordance with MIL-STD-414,[7] Level 4, and the sample shall be subjected to the rough handling test and freon leak test specified above in the

*The Flanders SUPER-FLOW (TM) separatorless filter is considered to be a satisfactory item for this purpose. It is a product of Flanders Filters, Inc., Washington, North Carolina.

filling method qualification test. The lot shall be rejected if any adsorber in the sample shall fail to meet the criteria of para 7.5.1 of AACC Standard CS-8. Rework of a rejected lot shall be permitted but a new sample will be required. A regular production lot shall consist of an essentially continuous production run and a single lot of adsorbent. The sample for the rough-handling test shall not be selected until the production of the represented lot is complete.

d. Adsorber performance shall be verified after installation by a freon leak test on each adsorber bank. The leakage rate of each bank shall not exceed 0.01% of the challenge concentration.

6. Adsorbent

The adsorbent for the adsorbers shall be coal-base or coconut-base activated charcoal meeting the specifications listed below. A 25-pound sample of each carbon lot shall be submitted to CSL for verification tests.

Specifications		Test Used
Iodine Number, Minimum*	1000	MIL-C-13724[8]
Carbon Tetrachloride Adsorption,* Minimum, % Weight	59	ASTM D3467[9]
Ash, Maximum, %	8.0	MIL-C-13274
Total Volatiles (150°C ± 50°C for 3 hours), %	4.0	MIL-C-13724
Hardness Number, Minimum	90	MIL-C-13724
Apparent Density (Bulk Density, Dense Packing), g/cc, Minimum	0.48	MIL-C-13724
lbs/ft.^{3}, Minimum	30.0	MIL-C-13724
Particle Size (3-Minute Shake Test):		ASTM D2862[10] and ASTM E323[11]

Sieve Size	Percent Retained
8 Mesh	0-5
8 x 12 Mesh	35-65
12 x 16 Mesh	35-65
16 Mesh	1-5 (through)

7. Blower Unit

a. The blower unit for each air-filter system shall be designed for vibration is ation by the use of flexible connections and isolation mountings and by proper balancing of components. Vibration isolation shall be required to minimize noise (see paragraph 1.f) and to reduce vibration to the extent that no damage shall be done to the filters and other equipment.

*Both of these tests are not required. The Carbon Tetrachloride Adsorption Test is preferred but the Iodine Number Test may be run as an alternative.

b. The blower shall be of good commercial quality designed to meet the specified volume airflow requirements stated in paragraph 1.d.

c. The blower fan shall be enclosed in a steel casing. Its shaft shall also be of steel and mounted on heavy-duty ball bearings. The bearings shall be sealed or contain readily accessible lubrication fittings. Both the intake and discharge openings shall be flanged.

d. The motor shall be of the totally enclosed, fan-cooled type with double-sealed, prelubricated ball bearings designed for continuous operation, and with a horsepower rating capable of driving the blower unit.

e. The motor, except for the 15,000-cfm air-filter system, shall be capable of operating from a 208 volt, 3 phase, 60 Hz power source.

f. The two motors for the 15,000-cfm air-filter system shall be capable of operating from a 460 volt, 3 phase, 60 Hz power source.

g. All motors 10 hp or larger are required to have an autotransformer-reduced voltage starter and capacitors across the motor providing a power factor of at least 0.90.

h. Exhaust stacks for the blower discharge shall be provided by the Government. The contractor shall provide a recommended configuration for the exhaust stack and all necessary information to enable the Government to properly join the exhaust stack to the blower discharge system.

8. Electrical

a. The contractor shall furnish one electrical contact closure on each air-filter system to provide a signal to a remote control panel when the specified air capacity is being pulled through the filter unit.

b. For each filter system the Government shall furnish motor starters and all wiring from the motor starter to the contractor-furnished disconnect switch. The disconnect switch shall be located in close proximity to the motor. The contractor shall provide a terminal block (also located in close proximity to the motor) and all control-function wiring for installation by the Government.

c. Provision shall be made by the contractor for a Government-furnished remote on/off switch. This switch shall allow automatic restart of the motor for each air-filter system after the loss of power without manual actuation.

9. Welding

All welding shall be in accordance with Section VIII, Division 1 of the ASME "Boiler and Pressure Vessel Code",[12] or in accordance with the military specifications listed below. Structural welding shall be in accordance with the ASME Code or AWS Standard D1.1, "Code for Structural Welding",[13] or the applicable military specification. For welds in material thinner than 1/4 in., the welder shall demonstrate his ability to make satisfactory welds in such material by making sample welds which shall be submitted to and approved by the purchaser's representative prior to the start of welding on such materials.

All welds on adsorbers and housings shall be made by personnel holding current qualification under Section IX of the ASME Code, AWS D1.1, or the applicable military specification for welding. Applicable military specifications are:

MIL-STD-1261[14]

MIL-W-8611[15]

MIL-W-12332[16]

MIL-W-46154[17]

LITERATURE CITED

1. MIL-STD-171, "Finishing of Metal and Wood Surfaces, "Dept. of Defense Military Standard, November 1972.

2. ARI Standard 680, "Standard for Air Filter Equipment," Air-Conditioning and Refrigeration Institute, 1970.

3. UL-900, "Safety Standard for Air Filter Units," Underwriters' Laboratories, 1971.

4. ASHRAE Standard 52-68, "Method of Testing Air Cleaning Devices Used in General Ventilation for Removing Particulate Matter", American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., August 1968.

5. AACC CS-1, "Standard for HEPA Filters", Institute of Environmental Sciences (Date unknown.)

6. AACC CS-8, "Standard for High Efficiency Gas Phase Adsorber Cells", Institute of Environmental Sciences, July 1972.

7. MIL-STD-414. "Sampling Procedures and Table for Inspection by Variables for Percent Defective", Dept. of Defense Military Standard, October 1968.

8. MIL-C-13724, "ASC, Impregnated, Activated Charcoal", Dept. of Defense Military Specification, September 1972.

9. ASTM D3467, "Method of Test for Carbon Tetrachloride Activity of Activated Carbon", 1976.

10. ASTM D2862, "Particle Size Distribution of Granular Activated Carbon", American Society for Testing and Materials, 1970.

11. ASTM E323, "Perforated Plate Sieves for Testing Purposes", American Society for Testing and Materials, 1970.

12. ASME "Boiler and Pressure Vessel Code," American Society of Mechanical Engineers, 1968.

13. AWS Standard D1.1, "Code for Structural Welding," American Welding Society, 1975.

14. MIL-STD-1261, "Welding Procedures for Constructional Steel," Dept. of Defense Military Standard, September 1968.

15. MIL-W-861, "Welding, Metal Arc and Gas Steels, and Corrosion and Heat-Resistant Alloys, Process For," Dept. of Defense Military Specification, July 1957.

16. MIL-W-12332, "Welding, Resistance, Spot, Seam and Projection, For Fabricating Assemblies of Low Carbon Steel," Dept. of Defense Military Specification, October 1968.

17. MIL-W-46154, "Welding, Resistance, Spot and Projection For Fabricating Assemblies of Carbon Steel Sheets," Dept. of Defense Military Specification, October 1970.

Appendix C

DETAILED ADSORBER BED CONSIDERATIONS

1. CAMDS Adsorber Cell

The CAMDS adsorber cell consists of a nominal charge of 50 pounds (22.7 kg) of activated carbon granules 8 x 16 mesh (0.179 cm dia) in size, having a cross-sectional area of 1,385 in.^{2} (8,937 cm^2) and a bed depth of 2 in. (5.08 cm). The filter has a flowrate of 333 cfm (9.424 m^3/min) at a superficial linear velocity of 10.54 m/min (17.57 cm/sec) and a mean residence time of 0.00482 min (0.289 sec). Three of these cells are placed in parallel when used in tandem with a 1,000-cfm HEPA filter.

2. General Characteristics of Adsorber Beds

When carbon granules are packed in a carbon bed, either by free fall or by bed vibration, they tend to pack in a manner similar to the hexagonal close packing of spheres. Thus, granules in the succeeding layer nest between the depressions created by granules in the preceding layer. If granules packed one on top of another it would be easy to show that, since the mean granule diameter of the 8 x 16 mesh is 0.179 cm, it would require the packing of 28 layers of such granules to make up the 5.08 cm bed depth indicated in the carbon cell. Because of the nesting characteristic of the carbon granules, a minimum of 28 layers of carbon granules exist in the CAMDS adsorber cell. Moreover, by knowing the internal area of the bed, its bed depth, and the carbon weight, one can calculate the bulk or packed density of the bed. In the CAMDS adsorber cell a charge of 22.7 kg carbon is packed in a volume of 4.54×10^4 cm^3, resulting in a bulk density of 0.50 g/cm^3. Since the true density of unactivated carbon is 2.15 g/cm^3 one can calculate from the relationship

$$\epsilon = 1 - \frac{\text{bulk density}}{\text{true density}} \qquad (1)$$

that the fractional void volume, ϵ, of the carbon granule bed in the CAMDS gas filter is 0.77.

3. Bed Calculations for Flow

Conceiving the packed bed of carbon granules as a multiplicity of narrow parallel channels, each packed with individual carbon granules, the effect on a flow of a gas-air mixture into the bed should be to straighten the volumetric flow into a series of parallel streamlines. Thus, it is possible to show that a bed area of 8,937 cm^2 subjected to a volumetric flowrate of 9.424 m^3/min experiences a superficial linear velocity of airflow of 10.54 m/min, and that with a bed depth of 5.08 cm the mean residence time of a slug of gas-air mixture, equal in volume to

the volume of the bed, is only 0.00482 min or 0.289 sec. Thus, the gas protection required of the carbon bed, measured in terms of the reduction of the inlet or challenge gas concentration to the insignificantly small gas concentration (below both detectable and physiological limits), must take place within 0.289 sec. The mechanism by which this occurs is essentially a first order process, and therefore one can conceive of a 28-step geometric progression, each succeeding carbon granule layer removing the gas penetrating the preceding layer with the same fractional gas adsorbing efficiency.

4. Concept of Gas Protection

The concept of gas adsorption by a bed of activated or impregnated carbon granules, resulting in protection against the gas challenge, is that a potential for spontaneously adsorbing the gas molecules exists in the carbon as a result of its activation process. The activation process is one which, under controlled conditions of heating in an inert atmosphere, creates a large internal pore surface area in the carbon. The effect of this large internal area, made up of many micropores with a radius of 50 Angstroms (5 nanometers) or less, is to manifest a true spontaneous adsorption, resulting in a decrease in free energy of the pore surface. The activated carbon then acts in a physical sense to adsorb gases by physical forces, without the need of a chemical change. This action, like other physical phenomena, can be described and quantified by ascribing both a capacity and an intensity factor to activate carbon, commonly known as its adsorption capacity and adsorption rate constant, respectively.

5. Adsorption Step Sequence

Klotz, in his manuscript on the adsorption wave in a carbon bed,[1*] showed that the process of gas adsorption occurs in a four-step sequence, namely,(1) bulk diffusion of the gas from its surrounding air to the outer surface of the carbon granule; (2) surface diffusion of the gas on the carbon outer surface to a pore mouth; (3) intragranular diffusion of the gas in the small pores of the carbon; and (4) physical adsorption of the gas molecule onto the active site of the micropore surface. Some authors describe step (1) as external diffusion, steps (2) and (3) as internal diffusion, and step (4) as the adsorption step. It is important in assessing the overall performance of a carbon bed in adsorbing gas from a flowing air stream to determine which of the above steps in the adsorption sequence is the slowest and, therefore, the rate-controlling step for the entire process. It is only by speeding up the slowest step in a sequence of steps that the overall rate of adsorption can be improved.

*See references listed at end of this appendix.

6. Breakthrough Characteristic of a Bed

The adsorption kinetics equation, which denotes the time at which a trace concentration exits a bed of carbon under specified test conditions, was derived by Wheeler[2] from a continuity equation of mass balance between the gas entering the bed and the sum of the gas adsorbed by the bed plus that penetrating the bed. The equation can be shown in the form modified by Jonas[3] as,

$$t_b = \frac{W_e}{C_o Q} \left[W = \frac{\rho_\beta Q \, \ln(C_o/C_x)}{k_v} \right] \tag{2}$$

where:

t_b = gas breakthrough time, in minutes

W_e = kinetic adsorption capacity, in g(agent)/g(carbon)

W = adsorbent weight, in grams

Q = volumetric flow rate, in cm^3/min.

ρ_β = bulk density of packed bed, in g/cm^3

C_o = inlet concentration of gas, in g/cm^3

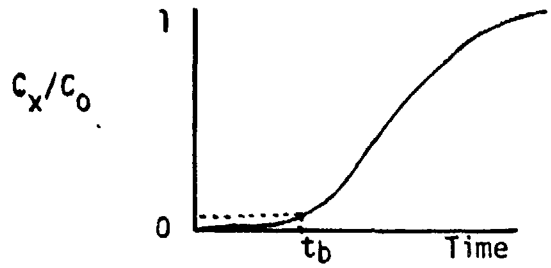
C_x = exit concentration of gas, in g/cm^3

k_v = pseudo first-order adsorption rate constant, in reciprocal minutes

By means of this equation the activated carbon to be used in a carbon cell can be characterized in the laboratory by determining its kinetic adsorption capacity (W_e) and adsorption rate constant (k_v) values. Knowing these two fundamental properties of the carbon, and inserting the test or use conditions of the carbon cell into the equation, it then becomes possible to calculate the protective life or breakthrough time of the carbon cell.

7. Bed Breakthrough Time Relations

It must be borne in mind that the breakthrough time of a bed, such as that obtained as t_b from equation (2) relates to the time at which an arbitrarily small concentration, C_x, breaks through the bed. The complete breakthrough curve of a carbon bed, when plotted against time, is an S-curve of the form,



When evaluating the protective life of a carbon bed against a toxic gas, one is interested in the time at which only a trace concentration penetrates (when C_x/C_o ratio is very small). This point is designated as t_b. In the case of a gas like GB, t_b is designated as the time when the exit stream shows the presence of a C_x/C_o ratio of about 10^{-5}. At this point in time (i.e., at this t_b), only 1 part in 100,000 parts of gas is penetrating the bed. Conversely, at this t_b the bed is still adsorbing 99.99999% of the gas challenging the bed. It takes a long time, in general, to get to the point in time when the carbon bed no longer protects in any way, i.e., no longer adsorbs any of the gas which challenges it, and thus shows a concentration penetrating the bed which is as high as that challenging the bed, i.e., when C_x/C_o equals 1. It is obvious that the absolute difference in time between t_b for a C_x/C_o of 10^{-5} and a t_b for C_x/C_o of 1 depends upon many factors, such as the challenge gas, the operating conditions, and the type of carbon used.

LITERATURE CITED

1. Klotz, I.M., Chemical Review, Vol. 39, p.241, 1946.

2. Wheeler, A. and Robell, A.J., Catalysis, Vol. 13, p. 299, 1969.

3. Jonas, L.A. and Rehrmann, J.A., "The Kinetics of Adsorption of Organo-Phosphorus Vapors from Air Mixtures by Activated Carbons," Carbon, pp. 657-663, 1972.

Appendix D

GENERAL CHARACTERISTICS OF ACTIVATED CARBON

1. Base Material

There are several different types of adsorbent used in the filtration field but the only type suitable for chemical demilitarization is activated carbon.

Coconut is the most widely used base material for activated carbon used in demil operations at this time. It is also used extensively in the nuclear field. Coal is the base material for most CBR military filters. Other base materials used with varying success in making activated carbons have been pecan nut, lignite, wood, and petroleum products.

Many of the physical properties desired of an activated carbon result from the type of base material used. A prime example of this is the hardness property of the carbon. Although anthracite coal is harder than bituminous coal it does not activate as well, and therefore the softer bituminous product is used. In addition, the physical and chemical composition of the base carbon material relative to, for example, the type, percentages, and location within the granule of the various hydrocarbons in its core, affect the type of activated carbon which can be developed from the base material.

2. Activation

The base material is activated in order to develop the extremely large internal surface area which gives activated carbon its gas-adsorbing properties. Activation processes vary in method and procedure but generally utilize a very mild oxidizer, under high temperature and in an inert atmosphere, to drive off an inner core of carbonaceous material which leaves behind an internal surface area within the carbon granule. The internal area may approach 2,000 m^2/g. Some examples of mild oxidizers used in activation are zinc chloride, steam, and carbon dioxide.

The process of activation creates a series of internal pores in the carbon granules. Those pores having diameters of 100 Angstroms (10 nm) or less are called micropores and are responsible for the major portion of the total internal surface area of the activated carbon. Larger pores (macropores) are needed to provide easy access to the micropores on whose surfaces adsorption takes place. Both the pore size distribution and the total internal pore surface area of the carbon contribute to the gas adsorption properties of the activated carbon.

Activated carbon is capable of retaining GB, VX, and mustard. It has an affinity for these agents and their vapors, which are readily adsorbed and held on the carbon. There are chemical agents and vapors which are not readily retained on activated carbon, however, and special treatment of the carbon is required for effective adsorption of these agents.

3. Specialized Treatment

Although the pore size distribution and internal surface area of an activated carbon determine its ability to adsorb gases or vapors under equilibrium conditions, the adsorption properties of the carbon may be drastically altered under dynamic flow conditions. Differences between potential and actual adsorption behavior are due to differences in diffusional or other rate-controlling steps in adsorption and/or differences in the affinity of the carbon for various vapors.

To augment the adsorption properties of a carbon for a specific vapor under dynamic flow conditions, where the spread between the potential and kinetic adsorption is large, a carbon may be impregnated with metals or metallic salts which cause chemical reactions to take place on the carbon surface after initial adsorption. The military impregnates its activated carbon with mixtures of copper, silver, and chromium salts (ASC whetlerite carbon) to enhance its effectiveness against hydrogen cyanide, phosgene, and cyanogen chloride vapors.

4. Hardness

Attrition and crushing of carbon granules under service conditions can result in dusting and subsequent escape of contaminated carbon, or in channeling through the bed with subsequent leakage of contaminated air or gas from the adsorber. Very hard carbons are desirable to resist fracture, abrasion, and crushing; a minimum ball-pan hardness of 92% is recommended. To minimize service degradation, vibration and pulsation in the air handling system must be controlled and minimized.

5. Surface Area

The internal network of pores within the carbon granule provides the large active area which gives the carbon its potential for adsorbing gases and vapors. A measure of the size or extent of the internal surface area or unit weight of an activated carbon is the carbon tetrachloride test, described in ASTM Standard D3467[1*]. This test measures the maximum amount of carbon tetrachloride that a unit weight of the activated carbon can adsorb at the fixed temperature of test, 25° C, and at the vapor concentration of 250 milligrams carbon tetrachloride per liter of air.

*See references listed at end of this appendix.

6. Mesh Size

The particle (mesh) size distribution of the adsorbent is limited by the open areas of the adsorber cell's perforated metal screens. The smaller the mesh size, the higher the pressure drop through the adsorbent. However, the smallest particle size must be larger than the screen openings or the particles will fall through the screens. The smallest holes that can be produced in a reasonably stiff screen material (26 gage) is about 18 mesh. Therefore, the smallest permissible particle size is 16 mesh. Adsorbent of 8 x 16 mesh is used to get good packing density. For some CBR applications, a fines cloth is inserted inside the screen to enable a 12 x 20 mesh adsorbent to be used.

7. Density

There are three densities associated with carbon granules. The true or real density of carbon before activation is 2.15 g/cm^3. After activation, which removes a large portion of the inner core of the carbon and produces the large internal surface area associated with an activated carbon, the density of the activated carbon granules decreases to about 0.85 g/cm^3. When activated carbon granules are packed in a bed, the apparent bulk or packed density of the bed is on the order of 0.48 g/cm^3 because of inter-particle voids. The packed-bed density takes into account both the intragranular spaces in a carbon granule (due to internal surface area) and the intergranular spaces or void volume (due to granule packing configuration).

The effect of packed density on carbon adsorption performance is complex. In accord with the density parameter in the gas adsorption kinetics equation, a decrease in packed density should decrease the critical bed layer or the required weight of carbon, other things being equal, and thereby improve adsorption performance. This situation exists as long as diffusion remains rate-controlling in the overall adsorption process. The underlying rationale for this is that increasing the open space between carbon granules provides gas molecules easier access and a longer time (increased residence time) to contact all available outer surfaces of the exposed carbon granules. Theoretically, if the adsorption process itself becomes rate-controlling, further decrease in packed density could have a deleterious effect on the overall adsorption performance.

8. Bed Weight

Since only a finite number of active sites can be developed within the micropores of an activated carbon during activation, the greater the weight of carbon for a given level of activation, the greater will be the adsorption capacity of the carbon bed. The protective time of a carbon bed against a vapor is normally considered the time at which a known trace of gas or vapor breaks through the bed when challenged

by a high inlet gas concentration under specific test conditions. Protective time varies directly with the weight of carbon.

9. Bed Depth

The effect of bed depth on adsorption performance cannot easily be separated from the more basic parameter of bed weight. For example, if bed area and packing density remain constant, an increase in bed depth is reflected in an increase in bed weight, thus resulting in improved adsorption performance. Some of the early mathematical equations of adsorption kinetics theory were developed on the basis of bed depth. Simple interconversion between these equations is possible through the relationship that the product of bed depth and bed area equals bed volume, and the product of bed volume and packing density equals bed weight.

10. Bed Volume

Assuming constant flowrate, the effect of bed volume on adsorption performance is coupled either to its relationship to bed weight of the carbon, in which case an increase in bed volume and weight causes an increase in adsorption performance, or to its packing density. The effect of changes in packing density on adsorbent performance is a separate consideration.

11. Volumetric Flowrate

The effect of volumetric flowrate on adsorption performance was previously regarded as an inverse relationship; namely, that when volumetric flowrate is increased, performance or protective life decreases. The decrease was considered due to two factors: (a) the increase in mass flux to the carbon, and (b) the increase in the critical carbon air-film layer which decreases the size of the adsorptive effect layer of activated carbon. More recently, secondary effects which moderate this simple inverse relationship have been studied in terms of the superficial linear velocity parameter, which is directly calculable from the volumetric flowrate. The relationship of the kinetic adsorption rate coefficient to the superficial linear velocity and its effect on performance have been reported on by Jonas and Rehrmann.[2]

12. Linear Velocity

The superficial linear velocity through a carbon bed is obtained by dividing the cross-sectional area of the bed into the volumetric flowrate. For a fixed cross-sectional bed area, an increase in volumetric flowrate causes a corresponding increase in the superficial linear flow velocity. Although the effects of volumetric flowrate increase are noted above, a moderating effect has recently been observed in that higher linear velocities tend to decrease or shear away the

thickness of the air film surrounding packed carbon granules and thus permit a more rapid transfer of gas from the fluid air stream to the outer surface of the carbon granules. This increased transfer rate manifests itself in an increase in the adsorption rate constant of the carbon. An increase in this rate constant tends to decrease the size of the critical bed layer, thus moderating the otherwise deleterious effect of increased flowrate.

13. Gas Residence Time

The concept of a mean residence time for a gas in the carbon bed is based on the approximation of plug flow of the air-gas mixture through the bed. Residence time is calculated by dividing the superficial linear velocity into bed depth, or by dividing the volumetric flowrate into bed volume. The mean residence time is that time for a volume of gas-air mixture equal in volume to the volume of the carbon bed to completely pass through the bed. The adsorption performance of a bed is increased as residence time is increased so long as the rate-controlling process of the gas removal is a diffusional mechanism. This has been the general result in studies of the physical adsorption of agents GB, VX, and HD.

A need exists, however, for a nondestructive method of determining the residual protective capacity of a carbon bed. The underlying concept for such a method is that gas adsorption by a bed of activated carbon granules is an additive phenomenon, each increment of adsorption adding to the previous one and thereby decreasing the remaining adsorptive capacity. Recent progress has been made on a method whereby a pulse of a difficultly adsorbable gas is sent into the carbon bed, and the retention time of the gas in the bed is determined. As portions of the carbon bed are saturated with more highly adsorbable gases, fewer active sites remain for temporarily holding the pulse gas and so the retention time of the carbon for the pulse gas decreases. By correlating pulse gas retention time with the degree of prior bed saturation, a calibration correlation can be made which relates to the retention time of the gas pulse to the residual protective life of the carbon bed.

14. Challenge Gas Concentration

The effect of an increase in challenge or inlet gas concentration is to decrease adsorption performance and protective life of the carbon bed. This occurs because the unit weight of activated carbon has a finite adsorption capacity, by weight, for a given gas. An increase in gas concentration, with volumetric flowrate constant, decreases the time at which the bed reaches its adsorption capacity, and therefore decreases its protective life.

Adsorption performance of an activated carbon is dependent on the test or use conditions under which the gas challenges the carbon. The effects on the performance of an activated carbon of the various parameters enumerated here have been incorporated into the theory of adsorption kinetics and can be found in mathematical equations developed from the theory.

15. Exit Gas Concentration

An increase in permissible exit gas concentration, other parameters being equal, is reflected in an increase in the protective life or adsorption performance of the carbon bed. The increase in protective life increases as in the logarithm of the increase in exit gas concentration.

16. Temperature

Physical adsorption of a gas by activated carbon is enhanced when the temperature is decreased. In the case of an impregnated carbon, such as ASC whetlerite carbon, in which protection is achieved by means of an initial physical adsorption followed by chemical reaction, an increase in temperature decreases the physical adsorption portion but may increase the chemical reaction portion of the overall sorption process. The overall effect of an increased temperature, therefore, depends upon whether physical adsorption or chemical reaction are rate controlling in the gas removal procedure.

17. Altitude

Higher altitudes, and the accompanying decrease in barometric pressure, decrease the ability of an activated carbon to adsorb a gas or vapor. The same effect also pertains for any chemical reaction occurring subsequent to the physical adsorption.

18. Water Vapor and Other Gas Contaminants

Water vapor tends to occupy adsorption sites on the carbon and, therefore, decreases the total amount of gas which can be adsorbed and the service life of the bed. The effect of other gas contaminants is the same, that is, they "poison" the carbon. The prior adsorption of a contaminant gas reduces the number of active sites or adsorption spaces which otherwise would have been available for adsorption of the gas or gases of primary interest.

19. Shelf Life

Shelf life *per se* has no deleterious effect on the ability of activated carbon to adsorb gases by physical adsorption processes. This is based on the assumption that the activated carbon can be stored in the dry condition (less than 2% moisture) in a closed

container. When stored in this condition, activated carbon has been shown capable of adsorbing gas, without decrease in efficiency, after 25 years of storage. There could be degradation of chemically impregnated carbons, however, due to the deleterious effects which normally result when impregnated carbons (activated carbon impregnated with metallic salts) are stored in the presence of high-moisture content and at elevated temperatures. Conditions such as these promote chemical reaction between the impregnated salts, water, and carbon.

20. Exposure to Dust

Since activated carbons cannot adsorb dust or other particulate matter from the atmosphere, the only possible effect of the dust would be to physically coat portions of the carbon granules or the spaces between the granules. The forces holding such dust particles are very weak dipole-type forces, causing the dust to be easily dislodged or shaken free. However, dust particles can plug the interstitial spaces between the carbon granules, thereby impairing the access of gas to the active sites on the carbon and significantly increasing the pressure drop across the bed. In most protective systems, the gas adsorber is preceded by a prefilter and/or HEPA filter which are designed to prevent the passage of dust into the adsorber beds.

LITERATURE CITED

1. ASTM D3467, "Method of Test for Carbon Tetrachloride Activity of Activated Carbon," 1976.

2. Jonas, L.R. and J.A. Rehrmann, "The Rate of Gas Adsorption by Activated Carbon," Carbon, Vol. 12, pp. 95-101, 1974.

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